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PHYSICS OF THE HOME

PHYSICS OF THE HOME

A TEXTBOOK FOR STUDENTS OF HOME ECONOMICS

BY

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SECOND EDITION
SECOND IMPRESSION

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PREFACE TO THE SECOND EDITION

This second edition contains no major changes. There has been a rewording of the topics in some instances and a few topics have been modified in the interest of a simpler treatment. The topics on home lighting have been placed just after the chapter dealing with light measurement rather than at the end of the chapters on light. The line drawings have been redrawn and some few new illustrations added. Each main topic has illustrative problems and each chapter has a condensed review summary.

To Dr. Kirsten Larssen Newbury and, again, to my wife, I am indebted for a careful reading of the manuscript.

F. A. Osborn

University of Washington,
Seattle, Washington.
September, 1929.

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Figs. 2, 3, 4. U. S. Bureau of Standards.

Fig. 6. Weights and Measures Department, City of Seattle, Wash.

Fig. 21. Eden Washer Corporation, New York, N. Y.

Fig. 22. Altorfer Bros. Co., Peoria, Ill.

Fig. 23. Laundreyette Manufacturing Co., Cleveland, Ohio.

Figs. 35, 36, 37. Singer Sewing Machine Co., New York.

Fig. 44. Seattle Lighting Co., Seattle, Wash.

Fig. 50. Poole Electric Co., Seattle, Wash.

Figs. 63, 99, 100. Taylor Instrument Co., Rochester, N. Y.

Figs. 74, 75, 76. Burgess-Parr Co., Moline, Ill.

Fig. 81. Pressure Cooker Co., Denver, Colo.

Fig. 83. Frigidaire Co., Seattle, Wash.

Fig. 90. Tappan Stove Co., Mansfield, Ohio.

Figs. 91, 92. McCray Refrigerator Co., Kendallville, Ind.

Figs. 105, 107, 108, 109, 110, 120, 121*a*, *b*, *c*, *d*. National Lamp Works, General Electric Co., Cleveland, Ohio.

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Fig. 184. Fobes Co. Seattle, Wash.

Figs. 185, 191, 192, 193. Edison Electric Appliance Co., Chicago, Ill.

Fig. 186. Western Electric Co., Chicago, Ill.

Fig. 192*a*. Dover Manufacturing Co., Canel Dover, Ohio.

Figs. 192*b*, 194, 196, 198. Westinghouse Electric and Manufacturing Co., Seattle, Wash.

Fig. 190. Waters Genter Co., Minneapolis, Minn.

Fig. 195. Electric Heating and Manufacturing Co., Seattle, Wash.

Fig. 206. National Carbon Co., New York, N. Y.

Figs. 212, 213. Graybar Co., Seattle, Wash.

PREFACE TO THE FIRST EDITION

The "Physics of the Home" has grown out of a course given to sophomore women in the Department of Home Economics. From the beginning the course has attempted not so much to present the usual general physics with illustrations drawn from the home as the chief difference, as to make the physics a real tool for the students. It has aimed to give a groundwork of principles from which the applications would come, and not to offer a course largely descriptive.

In the 10 years that the course has been given, there has been a constant addition, elimination, modification, and change of order in the topics treated. While it is too much to expect that either the topics discussed and omitted, or the different methods of treatment of the various topics, will meet the approval of all, nevertheless it is the belief that the text is a teachable one and will meet the needs of the students for whom it is intended.

As given at the University of Washington, the course is a two-quarter course of three lectures, one recitation, and one 3-hour laboratory period per week. It is given to sophomore women in Home Economics and in the College of Liberal Arts, some of whom have not had a year of high-school physics. By increasing the time exposure, giving the course for 36 weeks, it could be taken by senior girls in the high school.

The reception the course has received from the students in Home Economics and in Liberal Arts and from teachers of high-school home economics taking the course in the summer session, leads the author to believe that there is a real need for a text of this kind.

"Physics of the Home" is offered as the first formal attempt to meet the needs of women students who want to know physics not for its own sake but for its real help in their daily life. I shall feel more than grateful if my attempt is found in any degree to have subserved this purpose.

The author's thanks are due to many for permission to use the illustrations for which specific acknowledgment is made elsewhere.

To Dr. H. H. Lester, my colleague, and to Mrs. Lester, the author is indebted for a careful reading and helpful criticism of the original manuscript, and to my colleague, Prof. H. L. Brakel, for criticism and suggestions on the chapters on Electricity. To my wife, Mary L. Osborn, I am greatly indebted for the excision of many awkward English constructions and for her painstaking reading of the final manuscript.

To the many students in Home Economics of the University whose attitude toward the course in the "Physics of the Home" has furnished the inspiration for the writing of this text, the author makes grateful acknowledgment.

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INTRODUCTION

Measurements in the Home.—Household measurements suggest many interesting phases of the art of measurement. The significance of measurements in our civilization and their effect upon everyday life may not be fully appreciated. From the beginning of life measurement is important. The infant should weigh about so much, and the number of pounds is one measure of its condition. Its weight should increase at a normal rate, and here the weight becomes an index of nutrition and good health. The measure of the body temperature is an advance indicator of illness. Especially in recent scientific studies of childhood is the importance of measurement keenly realized. The response of muscles and nerves, the measure of the so-called time reactions and sense perception, are elements in studying educational methods, especially as applied to subnormal cases. It is possible to set certain approximate standards for the normal child and its growth. Measurements are made of the speed, strength, and fatigue of its reactions; of its height, girth, and other dimensions. Measurements in the future are going to play a more important part in directing the education of the young.

The progress of measurements into all the activities of the home has been slow, but the modern housekeeper is more and more discarding guesswork and vague units of quantity for definitely measured quantities. The "dash of seasoning," the "pinch of salt," the "soft ball" of syrup, the hand as an indicator of oven temperature are disappearing as it is realized that much of the failure to secure uniform and satisfactory results come from these indefinite measures.

The gas and electricity brought into the home have always been carefully measured. In recent years many cities demand that the wood, coal, and water shall be supplied in definite amounts. The housewife, while accepting these and often,

in the case of the gas and electricity, watching the meter very closely, has paid little or no attention to the matter of checking the *amounts* of other commodities received. The weights and measures departments, now established in many states, have helped greatly in securing full measure and correct weight. They all need, however, the active assistance of the housekeeper, if their work is to be of the greatest value. In a certain city whose homes used 6,000,000 lb. of butter per year, it was found by the weights and measures department that the housekeepers had been receiving on the average 15 oz. of butter for a pound. At 35 cts. a pound, they had been losing each year $131,250.

The pure-food laws have helped to establish definite measurements of the *quality* as well as the *quantity* of packed foods. But in the matter of fabrics used for clothing, and the materials used for home decoration, quality measurements are almost unknown. A seemingly high-grade heavy silk receives a good part of its weight from the addition of metals; all wool, long fiber, is found to be part wool or shoddy wool. The home maker should demand from the government a law that will as definitely specify the quality of materials as is now done for the quality of foods.

This introduction has called attention to the importance in the home in some of the general fields. The student will realize as she continues the study of the physics of the home that it is a continued application of measurement to the home problems.

MECHANICS AND SOUND

PHYSICS OF THE HOME

CHAPTER I

STANDARDS OF MEASUREMENT

1. Standards of Length.—The standards of length used by the different nations in the early times, while differing greatly, had a common origin: they were based on the proportions of the human body. Every man had his own scale to which he could work. The digit or finger breadth was one of the very earliest of these individual units of length. The foot, a unit derived from the length of the human foot, was as individual in value as the digit.

In the reign of Henry III, in the thirteenth century, the following relations were established by statute:

"It is ordained that 3 grains of barley, dry and round, make an inch; 12 inches make a foot; 3 feet make a cubit (yard); etc." The inch so established from three barleycorns laid end to end or eight side by side, has been forgotten. But our yardsticks still have the inches divided into eight parts, and the shoemaker's tape measures the sizes of shoes by a barley corn—that is, $\frac{1}{3}$ in. A No. 3 woman's shoe measures $8\frac{1}{3}$ in., a No. 4 shoe $8\frac{2}{3}$ in.

During the early years of our country, the standards of weights and measures were more or less accurate copies of the ones that had come to be used in England. On the burning of the Parliament buildings in 1834, the English standards were destroyed, and in 1855 a new imperial standard yard was adopted. This was a solid square bar of special bronze, 38 in. long and 1 in. square. Near each end of the bar a hole was bored to a depth of about $\frac{1}{2}$ in., and at the bottom was inserted a gold plug on which a line was scratched. By act

of Parliament the distance between these two lines, when the bar is at a temperature of 62° F. is the imperial yard of 36 in. A copy of this standard, known as Bronze Standard No. 11, was presented to the United States. It is 0.000088 in. shorter than the imperial standard. This bar became the standard of length for the United States.

The English standards of length and mass are arbitrary and their perpetuity must depend upon the care with which they are preserved. The main objection to these standards, however, is that they are not based on a decimal system.

During the last year of the eighteenth century the subject of a rational system of weights and measures was largely discussed in France. A natural unit of length was sought, one that would not change; and the French Academy of Science recommended the length of the earth's meridian from the equator to the pole. A definite part of this distance was carefully measured and the difference in latitude between the two measured points was found. The distance of 1 deg. could now be computed and then the length for 90 deg. One-ten-millionth of this length was to be taken as the meter. It has since been found that the quadrant is longer than then determined, so the actual meter is the distance between two transverse lines on a platinum-iridium bar at 0° C. This bar is kept in the International Metric Bureau at Sevres. Our present English units of length are determined from this standard meter. The relations between the two, as fixed by law, are given in **Art. 4.** The standard meter for the United States is known as Prototype Meter No. 27.

2. Standards of Mass.—The history of the standard mass is as interesting as that of the standard length, but it cannot be given here. The standard of mass for the United States is a certain platinum mass known as the United States prototype kilogram. Our English units of mass are obtained from this by the relations given in **Art. 4,** which were fixed by law.

The French standard kilogram was originally assumed to be the mass of 1,000 c.c. of pure water at 4° C. The actual platinum mass is 0.04 mg. heavier and so the kilo-

gram standard is an arbitrary one, as is the actual standard of length.

3. Standards of Time.—The unit of time is the mean solar second. A solar day is defined as the interval between the passages of the sun across the meridian. As these intervals are not equal, the mean of these intervals for 1 year, which has been found not to vary from year to year, is taken as the time of a mean solar day. From this time and the relations that a mean solar day is divided into 24 hours, the hour into 60 min. and the minute into 60 sec., the mean solar second is defined as 1/86,400 of the time of a mean solar day.

The mean *local* time of every place would differ from that of every other place except for the points on the north and south line through that place. The *mean local time* changes about 5 sec. for each mile, so the east and west boundaries of a large city 12 miles distant from each other, would have *true local times differing* by a whole minute. This confusion in the time of nearby places led to the establishment of standard time sections. The United States is divided into four sections, called the Eastern, Central, Mountain, and Pacific sections. The approximate centers of these sections are the following meridians of longitude: seventy-fifth, ninetieth, one hundred and fifth, and one hundred and twentieth.

All the clocks in any one section should, if correct, indicate the same standard time and the difference between the clocks in adjoining sections would be 1 hour. The difference between Pacific and Eastern standard clock time is 3 hours. The 15 degress of difference between the meridians is equal to one-twenty-fourth of a rotation of the earth, hence the time in each section differs from that in an adjacent section by just one hour.

The United States Naval Observatory sends out time at noon and 10 p.m., Eastern standard time. On the Pacific Coast the correct standard time is then 9 a.m. and 7 p.m. The Mare Island Observatory, California, sends out time daily at noon and 10 p.m. Pacific standard time. The telegraph offices in the larger cities and the railroad stations in the smaller places usually receive these time signals.

4. Relation between the English and Metric Units:

1 in. = 2.54 cm.*	1 cm. = 0.3937 in.
1 ft. = 30.48 cm.	1 m. = 39.37 in. (1.094 yd.)*
1 yd. = 91.44 cm.	1 km. = 0.6214 mile
1 mi. = 1.609 km.	
1 sq. in. = 6.45 sq. cm.	1 sq. cm. = 0.1550 sq. in.
1 sq. ft. = 929.03 sq. cm.	1 sq. m. = 1.196 sq. yd.
1 sq. yd. = 0.8361 sq. m.	
1 cu. in. = 16.387 cc.	1 cc. = 0.061 cu. in.
1 cu. ft. = 0.02832 c.m.	1 cu. m. = 1.308 cu. yd.
1 qt. = 0.9463 l.	1 l. = 1.057 qt.*
1 gr. = 64.8 mg.	1 g. = 15.44 gr.
1 oz. av. = 28.35 g.	1 g. = 0.0353 oz.
1 lb. av. = 453.59 g.*	1 kg. = 2.204 lb.*

The student is expected to know the relations starred (*) in the above table.

5. The Three Fundamental Units.—All volume or capacity measurements as well as those of area may be reduced to simple measurements of length; a volume is the product of three lengths; an area, the product of two lengths. A meter or yardstick is then the one necessary instrument for the determination of any of these quantities. Units of volume and area are often called *derived* units as they depend upon the one *fundamental* unit of length.

The units of time and mass require a clock and a balance for their measurements, each instrument being distinct from the other.

The measurement of the pressure in a steam cooker, the velocity of the small wheel on a sewing machine, the amount of electricity used in a toaster, etc., can all be reduced to measurements of length, time, and mass. Hence these are considered as the fundamental units, and the measurement of any quantity in terms of these is said to be expressed in *absolute* units. If, as in all scientific work, the centimeter, gram, and second are used, the measurement is said to be in the c.g.s. (centimeter-gram-second) system.

6. Weight and Capacity—Household Measures.—The careful housekeeper will check the weight of all purchases and for this purpose some type of scale or balance is necessary.

The equal-arm balance (Fig. 1) is a reliable form of scale, but has some disadvantages. It is costly, loose weights or a sliding poise are required, and the weighing cannot be made quickly.

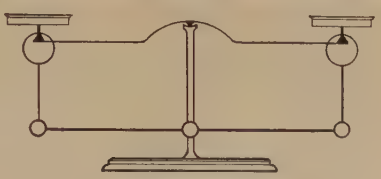


Fig. 1.—Equal-arm balance.

In Figs. 2 and 3 are shown a diagram of the construction and a picture of a complete scale. This is the spring-balance type and is made in many forms. It has a capacity of 10 to 20 lb., requires no weights, is quickly and easily read, is fairly accurate, and not unreasonable in cost.

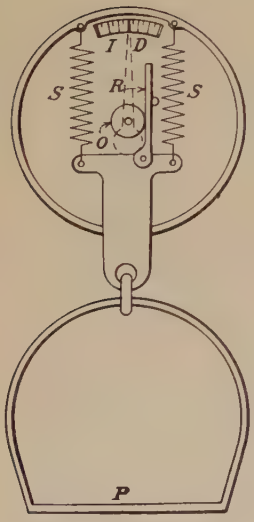


Fig. 2.—Diagram of spring balance.

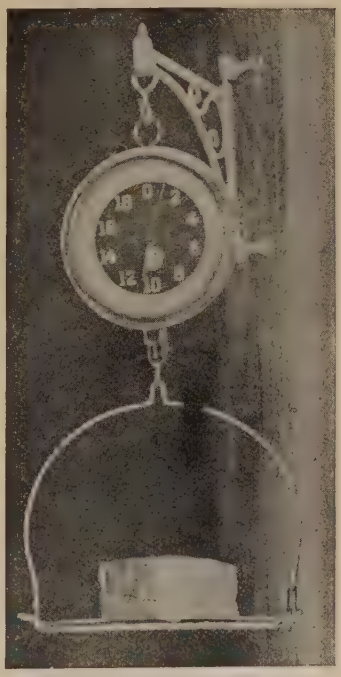


Fig. 3.—A spring balance scale.

Another type of balance which has the advantages of the equal arm balance and the spring scale is shown in Fig. 4. This scale is made in styles designed expressly for household use.

The so-called "family scale" shown in Fig. 5 finds a too ready place in many homes. This style may be purchased for as little as $1, and in the cheaper forms is so inaccurate as to be

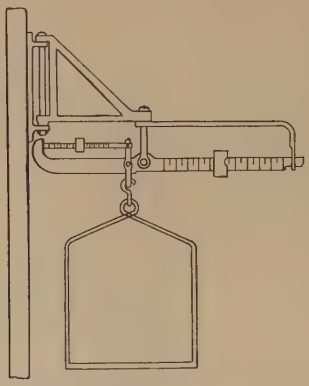


FIG. 4.—Folding household balance of steelyard type.

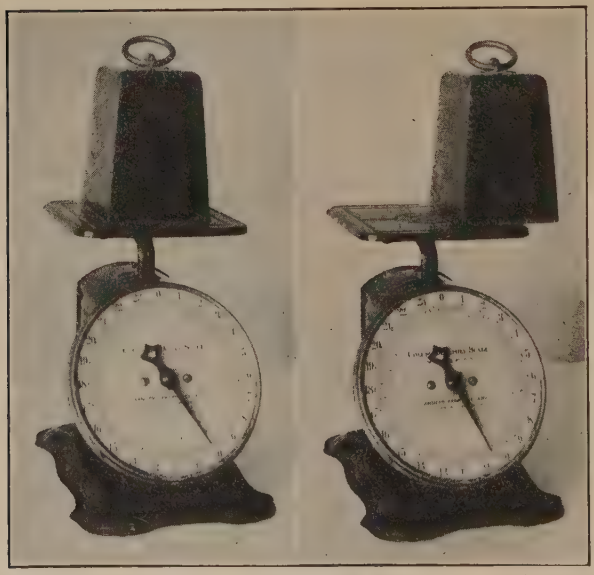


FIG. 5.—A family scale indicating that the reading may depend upon the position of the load.

worthless. Unless very well made and costing nearly as much as the styles above, they are unsatisfactory.

FIG. 6.—A few scales confiscated by a Weights and Measures Department because they were giving false weights.

The *standard* cup is the basis of many measurements in the kitchen.

The standard cup holds 8 *fluid* ounces or ½ liquid pint and is used to measure both liquid and dry commodities.

The illustration shows some convenient and satisfactory measuring devices for the kitchen.

FIG. 7.—Measures used in the kitchen.

7. Equivalents of the Common Capacity Units Used in the Kitchen:

CAPACITY MEASURES

Units	Fluid drams	Teaspoonfuls	Tablespoonfuls	Fluid ounces	¼ cupfuls	Gills (½ cupfuls)	Cupfuls	Liquid pints	Liquid quarts	Cubic centimeters	Liters
1 fluid dram equals	1	¾	¼	⅛	1/16	1/32	1/64	1/128	1/256	3.7	0.004
1 teaspoonful equals	1⅓	1	⅓	1/6	1/12	1/24	1/48	1/96	1/192	4.9	0.005
1 tablespoonful equals	4	3	1	½	¼	⅛	1/16	1/32	1/64	15	0.015
1 fluid ounce equals	8	6	2	1	½	¼	⅛	1/16	1/32	30	0.030
¼ cupful equals	16	12	4	2	1	½	¼	⅛	1/16	59	0.059
1 gill (½ cupful) equals	32	24	8	4	2	1	½	¼	⅛	118	0.118
1 cupful equals	64	48	16	8	4	2	1	½	¼	237	0.237
1 liquid pint equals	128	96	32	16	8	4	2	1	½	473	0.473
1 liquid quart equals	256	192	64	32	16	8	4	2	1	946	0.946
1 cubic centimeter equals	0.27	0.20	0.068	0.034	0.017	0.0084	0.0042	0.0021	0.0011	1	1/1,000
1 liter equals	270	203	67.6	33.8	16.9	8.45	4.23	2.11	1.06	1,000	1

Study Exercises

1. The dimensions of a door in a home are 79 by 30 in. Give the door size in centimeters; in meters.
2. A window size is given as 1.53 by 1.1 m. What are its dimensions in feet?
3. A certain recipe called for ½ pt. of milk. How many cubic centimeters of milk are required? What part of a liter?
4. If candy is selling for $1 a pound, what would be its price per kilogram?
5. A cake recipe called for: ½ cup of shortening, 1 cup of sugar, ¼ cup of milk, ⅛ pt. of water, ½ lb. of flour, 2 teaspoonfuls baking powder, and some eggs. Change these amounts into metric units.
6. If sugar sells in France for 18 cts. per kilogram and for 6 cts. per pound in the United States, in which country is it the cheaper?
7. A dress pattern contains 274.3 cm. How many yards were there in the pattern?
8. On a running track a student ran 0.268 km. in a minute. What was her speed in miles per hour?
9. A living room whose dimensions are to be expressed in the nearest whole meters is 15 by 12 by 9 ft. What is its size in meters?

Some Suggested Laboratory Exercises

1. Test of a cloth yard tape, dry, and after wetting and drying.
2. Study of a yard and meter stick relations.
3. Study of the construction, operation and errors in household scales.
4. Capacity determination of several milk bottles formerly in use in a certain city.
5. Capacity determinations of three different measuring cups.
6. Comparison of capacity of several different spoons with a set of standard spoons.
7. Cubic contents of different sizes of cans used for canned foods.

REVIEW SUMMARY

Brief account of units of length and mass.

Our legal units of length and mass established by Congress from the standard meter and kilogram; unit of time, local time and standard time. Time in the three divisions of United States.

Table of Metric and English Units.

Three fundamental units—length, mass, time, the absolute or c.g.s. system.

Types of household balances.

Table of capacity measures.

CHAPTER II

FORCE

8. Primary Idea of Force.—Our primary ideas of force come from muscular efforts. We lift a pail of water, we push a carpet sweeper, we pull a table. This lifting, pulling and pushing requires a muscular effort. We lift a flatiron, exerting a muscular effort, and place it on the stove. The stove now acts in place of our hand and exerts an upward push or force on the iron. A picture hangs on the wall, the supporting cord is pulling on the picture. In these illustrations we have the same *effects* of a pull or push without any muscular effort. Pushes and pulls, pressures, attractions and repulsions, whether produced by muscular efforts or otherwise, are called "forces."

9. Measurement of Force by Muscular Effort.—If we try to get an idea of the *amount* of a force from estimating the amount of muscular effort, we find that the same force is given different values under different conditions. The pull of a bucket of water seemingly increases as we continue to hold it. The muscular effort exerted by the iceman in putting the ice into the refrigerator is, to him, not great, but to the housewife it is very great. The force required is the same in each case.

If one holds a pail of lard in one hand and a potato in the other, it is easy to say that it requires a greater force to hold the pail of lard than it does to hold the potato, but even with considerable experience it would be difficult to estimate *how much more* the effort is in the one case than in the other. Quantitative estimation of force by muscular efforts is unreliable.

10. The Pound of Force.—Our everyday experience shows us that to lift bodies above the earth's surface requires an

effort or a force, and that it requires a greater force to lift the sack of flour than the sack of salt. We assume the cause of the pull on the flour or salt to be the attraction of the earth for matter, and we call a *pound of force the amount of the earth's pull or attraction at its surface upon a pound mass.*

11. Mass and Weight.—Unfortunately, in ordinary language, the terms "a pound of force" and a "pound of mass" are confused, since the same word "pound" is used for both. We speak of "a pound of butter" and "a pull of a pound." In the first case, we have in mind a certain *amount of matter*, and in the second case, the *pull of the earth upon this pound of matter*. That these two ideas are wholly different is seen if we consider these two facts. The amount of matter in a pound of butter is the same everywhere on the earth, but experiment shows that the pull of the earth on this pound of butter varies in different places on the earth. A pound force has then not the same value at all places, while a pound mass has.

The verb "to weigh" nearly always means to find the mass or amount of matter in a body. A 10-lb. weight or mass can exert a force of 10 lb. because it is attracted or pulled by the earth with a force of 10 lb. While the same word "pound" is used to designate a mass and a force, there is usually little trouble in determining which is meant, as the following illustrations show: The boy brought home 5 lb. of lard; the pull on the rope was 5 lb.; the 100-lb. girl exerted a force of 100 lb. upon the floor.

12. Measurement of Force.—One of the simplest methods of accurately measuring a force is to use the stretch of a spiral spring. If a mass of 1 lb. is hung from a spring, it will stretch it a definite amount, due to the pull of the earth on the mass, and the pull of the earth on a 2-lb. mass will stretch the spring twice as much. The stretch of a spring is proportional to the force acting on it, whether this force is due to the attraction of the earth for various masses or to the pull exerted on the spring by the hand. When a spring is provided with a pointer to indicate the amount of stretch, and a scale upon which have been marked the positions of the pointer for different

known masses hung on the spring, such a spring is then an instrument for measuring forces.

A spring thus calibrated may evidently be used to determine the amount of matter or the mass of an unknown body. For, if the body is hung on the spring which then reads 4.5 lb., we know that the attraction of the earth for the unknown mass is 4.5 lb. But from our definition of a pound of force, when the force of attraction of the earth is 4.5 lb. for a given mass, that mass must have 4.5 lb. of matter in it. Many of the scales in meat markets are of the spring type and indicate both the mass of the meat and the pull of the earth on the meat.

13. Force Effects and Characteristics.—Force effects are many, such as a change in a body's position, motion, shape, size, or physical state.

The *effect* of a given force acting on a body of given mass is known when the *point of application of the force* is known, its *direction*, and *magnitude*, and in the case of change of motion, the *time* the force acts.

The point of application of a force determines the *kind of motion* given to a body by the force. It may be a motion of translation, of rotation, or both, depending upon the point on the body at which the force acts. The push on the baby cart causes a motion of translation of the cart, but its effect on the rim of the wheel is to give the wheel a motion of rotation. A pull given to the bread mixer may cause a motion of translation of the mixer, but it is usually so applied as to cause a rotation of the handle.

A given push along the handle of the carpet sweeper increases its effect, moving the sweeper over the carpet, as the handle is made more nearly horizontal. When the handle makes an angle of 45 deg. with the horizontal the force effect is greater than when the angle is 60 deg.

To lift the body vertically as in climbing stairs requires a force; to go upstairs with an *increasing* speed requires a greater force. The force one exerts on the floor of the elevator is *equal* to one's weight when the elevator moves with uniform speed; *less* than one's weight when the elevator *descends* with

increasing speed; and *greater* than one's weight when *ascending* with *increasing* speed.

14. Composition and Resolution of Forces.—A single force or more than one may act on a given body. If two or more forces act on a body simultaneously the *final effect* is the *same* as if each force acted separately. A single force whose final effect is the same as the combined effects of the separate forces may replace the separate forces. It is called the *resultant* force and the several forces which are equivalent in their effects to the resultant are called the component forces.

Just as several forces may be replaced by an equivalent single force, so in general any single force may be replaced by two or more forces producing the same effect.

The illustrations show some applications of the general statements made concerning forces:

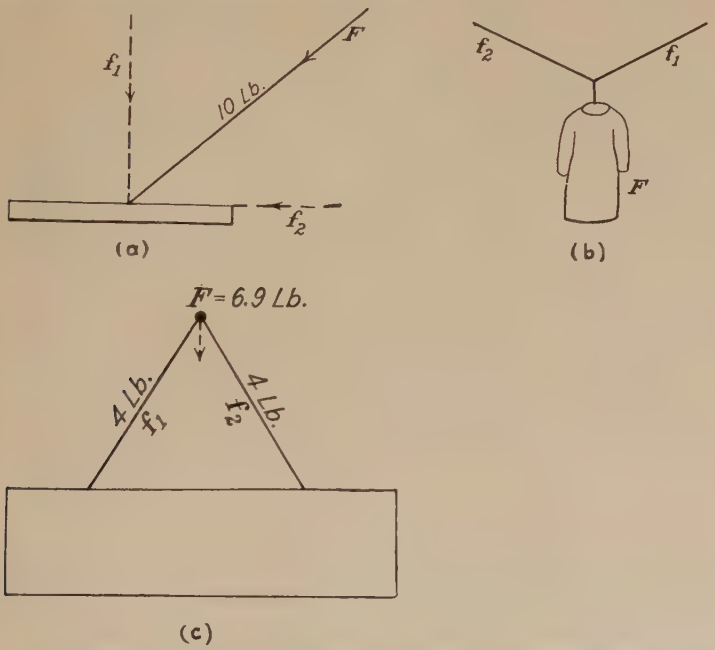


FIG. 8.—(a) Carpet sweeper. Force, F, along the handle resolved into forces f_1 and f_2. The force f_2 causes the motion of the sweeper. (b) Garment on a line. The weight of the garment pulls on the line with forces f_1 and f_2. (c) Picture on the wall. The two forces f_1 and f_2 due to the weight of the picture are balanced by one force, F, acting at the nail.

15. Graphical Solution for Components and Resultant. (*a*) *Resultant.*—Let AB and AC (Fig. 9) represent forces of 4 lb. each, acting at an angle of 60 deg. Complete the parallelogram by drawing BD and CD. Then the line AD represents the resultant and its magnitude can be found by measuring its length on the same scale of length as AB.

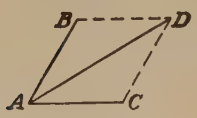


Fig. 9.

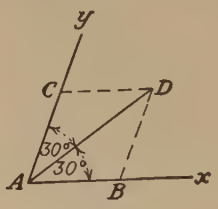


Fig. 10.

(*b*) *Components.*—A single force can be replaced by two components and the value of the components found from a graphical solution. Let AD (Fig. 10) be a given force of 10 lb.; find the value of the component forces which make angles of 30 deg. with AD. Draw lines Ax and Ay, each making a 30-deg. angle with AD, complete the parallelogram by drawing lines DC and DB. The intersection of these lines with Ay and Ax determines the lengths of the lines representing the two components. Measured on the same scale as $AD = 10$ units, the length of AB or AC is 5.77 units. The component forces are then 5.77 lb. each.

To find the components then by a graphical solution, we must know the angle between the two desired components and the angle *one* of them makes with the given force.

Illustrative Problems

1. Find the force parallel to the ground which is moving the lawn mower, when the force acting along the handle is 15 lb. and the handle makes an angle of 45 deg. with the ground.

Let the force along the handle be represented by the dotted line AB of length 1½ in. We are to resolve AB into two component forces at right angles to each other, AC being parallel to the ground so that angle BAC is 45 deg. Complete the parallelogram $ACBD$. Then AC, its

length measured on the scale of AB, ½ inch equals 5 lb., will represent the force acting to push the lawn mower along the ground. AC = 1.06 in. = 10.6 lb.

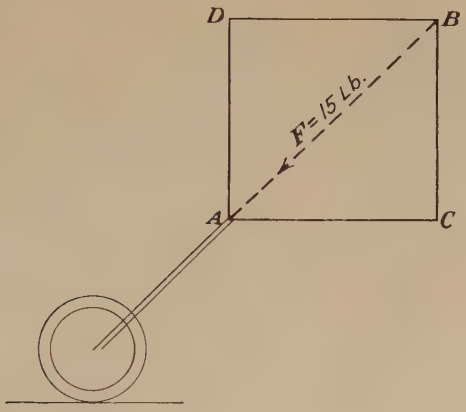


Fig. 11.

2. Find the pull on the parts of the clothesline due to the clothes of weight W.

The pulls P_1 and P_2 are to be found when their directions with respect to CD make the angles A and B.

Draw the line $W = C_1D_1$ whose length is to represent the weight of the clothes and the direction of the pull.

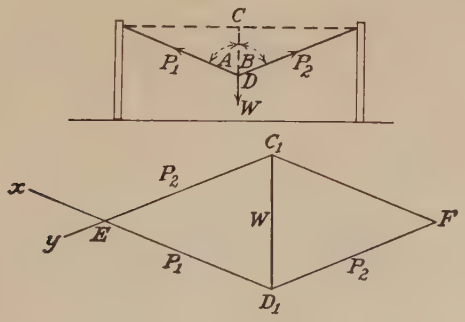


Fig. 12.

From D_1 draw the line D_1X of indefinite length but making at D_1 an angle equal to the angle A. From C_1 draw the line C_1Y of indefinite length but making at C_1 an angle equal to the angle B. The intersection

E of these two lines will determine their lengths and these lengths, measured in the same scale as $C_1D_1 = W$, will represent the two desired pulls on the line. It is evident that we have simply constructed a parallelogram FC_1ED_1, with C_1D_1 as the diagonal and D_1E and D_1F or C_1E the desired components.

3. Find the force required to hold the body B of mass 10 lb. on an inclined plane of height 5 ft. and length 15 ft.

Figure 13 represents an inclined plane whose height and length are proportional to 5 and 15. Let the pull of the earth on mass B be represented by the vertical line BW. The force required to hold B on this frictionless plane is a force equal and opposite to the component of the earth's pull parallel to the incline. BW is then to be resolved into two components, one parallel to the incline and the other perpendicular to it. Draw BC and AB, completing the parallelogram around BW. The length of AB measured on the same scale as $BW = 10$ lb. will give the required force. $AB = 3.33$ lb. The other component BC is evidently the force with which B pushes on the incline.

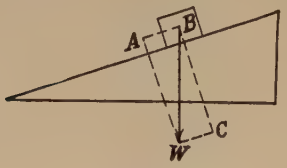


FIG. 13.

16. Inertia.—One of the distinguishing characteristics of matter is known as "inertia." A body has no ability within itself to change its state of rest or motion and therefore, if no outside forces act on it, a body at rest will remain at rest and a body in motion will continue indefinitely in uniform motion in a straight line.

Looking at this property from the standpoint of the body, inertia is the measure of the resistance a body offers to any change in its motion. The inertia of a body is proportional to its mass.

If a card is placed on a tumbler and a marble, on the card by a sudden flick of the finger the card can be removed from the glass without giving any horizontal motion to the marble. While the force applied for a *short time* may have been fairly large, the greater inertia of the marble enabled it to resist the action of the force. The card, of less inertia, yielded to the force. The inertia of matter not only makes it difficult to set a body in motion but also makes it difficult to stop a moving body.

The inertia of a person is shown by the violent jerk backwards experienced as the automobile is suddenly started, or the

difficulty in walking toward the rear of a street car as it is being brought to a stop. The familiar method of removing the dust from a carpet by beating also illustrates inertia. The blow causes the carpet to move away from the dust and the dust, remaining at rest, momentarily, because of its inertia, is blown away by the wind. The inertia of a body is proportional to its mass, and if a force acting on a body has only its inertia to overcome, a given force will produce a large change of motion on a small mass and a small change on a large mass. The force of the push that causes the dining-room table to move quickly will cause hardly any movement of the piano.

17. Force and Acceleration.—Newton stated that a force is required to change the motion of a body and that the *rate of change of momentum* is proportional to the force acting. The momentum of a body is equal to the product of its mass times its velocity. A mass of 10 lb. moving with a velocity of 10 ft. per second has a momentum of 100 units. Change of momentum is simply the difference between the body's momenta at different times. It may be expressed as $mv_1 - mv$. Rate of change of momentum is the change of momentum divided by the time during which the velocity changed or $\frac{mv_1 - mv}{t}$. For example, a 120-lb. woman is running with a velocity of 5 ft. per second but at the end of 5 sec. she is running at 2 ft. per second. Her rate of change of momentum is

$$\frac{(120 \times 5) - (120 \times 2)}{5} = 72 \text{ units.}$$

Then we may write,

Force is proportional to

$$\frac{\text{momentum at end} - \text{momentum at start}}{\text{time required to change the momentum}},$$

or

$$F \alpha \frac{mv_1 - mv}{t} \tag{1}$$

and

$$Ft \propto mv_1 - mv. \tag{2}$$

If the unit of force is so selected that it is unity when the mass, velocity change, and time are unity, then equation (1) may be written

$$F = \frac{mv_1 - mv}{t} \tag{3}$$

or

$$F = m\frac{(v_1 - v)}{t}.$$

We call the expression, $\frac{v_1 - v}{t}$, the rate of change of velocity or the *acceleration* a of the mass. Then

$$F = ma. \tag{4}$$

Equations (3) and (4) evidently give a way of measuring force other than by the pull of the earth on a pound mass. They define a unit force as that force which acting on a pound mass will give it a change of velocity of 1 ft. per second in a second, equation (3), or that force which will give a pound mass an acceleration of one foot per second per second, equation (4).

Let us compare the pound force with the force obtained from equations (3) or (4). If we hold a pound mass above the earth's surface, the earth exerts a pull on it of 1 lb. If we remove the support, the *force* of 1 lb., due to the earth's pull, will give the body a certain acceleration, differing slightly at different places on the earth's surface. This acceleration is very nearly equal to 32 ft. per second per second or to 980 cm. per second per second. Equations (3) and (4) state that when the force acting on unit mass is unity, the acceleration must be unity. But a pound force acting on a unit mass, 1 lb., will produce an acceleration of 32 ft. per second per second. It is evident then, that the pound force is thirty-two times larger than the force given by equation (3) or (4), and to use these equations to measure forces in the pound or gram force units, the right-hand term must be divided by 32 for the pound and 980 for the gram force.

Then

$$F \text{ (in pounds)} = \frac{m(v_1 - v)}{32t} = \frac{ma}{32}. \tag{5}$$

$$F \text{ (in grams)} = \frac{m(v_1 - v)}{980t} = \frac{ma}{980}. \tag{6}$$

When m in equation (5) is the mass in pounds, the velocities are in feet per second and time is in seconds, and in equation (6) m is in grams, the velocities in centimeters per second, and time is in seconds.

Equations (7) and (8):

$$Ft = m\frac{(v_1 - v)}{32} \tag{7}$$

and

$$Ft = m\frac{(v_1 - v)}{980}. \tag{8}$$

show that the change of momentum depends upon two factors, the force acting and the time it acts. Illustrations of this principle are numerous. The advantage of the rubber heel is due to the fact that the momentum of the body *downward* in walking is changed at each step to its zero value in a longer time with the rubber heel than with the leather heel. If $mv_1 - mv$ is the same and t is larger, then F is smaller; that is, the jar or blow to the body is less. Tile, cement floors, or hardwood floors are harder to walk and work on than a floor with cork coverings or one covered with a heavy rug, because the jar to the body at each step is greater. Marble, slate, or porcelain tops on the kitchen table or sink have some advantages, but the danger of breaking dishes is increased as the blow received by them on being quickly placed on these surfaces is greater than that received from the wood tops. Wrapping twine that is too strong to break with a steady pull can be rather easily broken if given a quick jerk. In this case, the time was too short to have much of the force expended in stretching the string, so a greater part was used in rupturing it.

Illustrative Problems

1. A baby cart, of mass 40 lb., moving with a velocity of 4 ft. per second has its motion reduced to zero in 2 sec. What force was acting?

The momentum of the cart was 4×40 and then 0, so the change of momentum was 160 and this was produced in 2 sec. The force in pounds, acting, was $160 \div (2 \times 32) = 2.5$ lb.

2. A 120-lb. person running at a speed of 10 ft. per second bumps into a tree. Assuming the time to stop the motion was ½ sec., what was the force of the blow? The change of momentum was 120(10–0) and the rate of change of momentum was $1{,}200 \div \frac{1}{2} = 2{,}400$. The force then was $\frac{2{,}400}{32} = 75$ lb.

3. A person falls on the cement walk and again on the lawn. Assuming the only difference in the two cases was that on the cement walk the time of stopping one's motion was one-third what it was on the lawn, what were the relative blows due to the falls?

Since the change of momentum was the same but the times were as 1:3, the forces were as 3:1, because $Ft = mv_1 - mv$.

4. A 120-lb. person standing on the floor of an elevator exerts a force of 120 lb. on the floor. If the elevator ascends with an acceleration of 5 ft. per second per second the elevator must give this acceleration to the person; that is, it must exert a force. What is the value of this force, and the total force action?

$F = \frac{120 \times 5}{32} = 18.7$ lb. This is the *extra force* to produce the change of motion. The earth's pull was 120 lb.; hence the *total* force acting was 120 + 18.7 or 138.7 lb.

5. A force of 50 g. acts for 5 sec. on a mass of 100 g. What change of velocity was produced?

$$50 = \frac{100V}{980 \times 5} \qquad V = 2{,}450 \text{ cm. per second.}$$

6. A 2,000-lb. automobile moving with a velocity of 30 miles per hour (44 ft. per second) is brought to rest in 5 sec. What force was applied?

$$F = \frac{2{,}000 \times 44}{5 \times 32} = 550 \text{ lb.}$$

18. Friction.—Whenever one body moves in contact with another, whether by sliding or by rolling, or whenever a body moves through a fluid, the body is always acted upon by dragging or hindering forces which tend to bring it to rest. These opposing forces are due to friction.

Friction forces are both useful and wasteful. Walking would be impossible without friction between the shoes and the floor. The ice-covered walk and the highly waxed floor both occasionally impress upon one the disadvantage of a poor friction surface. The friction between the broom and the

heavy rug is greater compared with that of the waxed floor. The small friction between the umbrella end and the floor makes it difficult to stand the umbrella in the corner. The friction of the paddles in the ice-cream freezer and of the bent rod in the bread mixer requires a greater force to be applied, but here the friction is desirable. If there were no friction between the blades of the egg-beater and the egg, there would be no beating of the egg. But the friction between the moving parts of machinery is always wasteful, requiring a greater force to operate the machine.

19. Sliding and Rolling Friction.—We are all familiar with the fact that a carriage rolls over the ground more easily than a body that is dragged over it. Rolling friction is less than sliding friction. In the case of wrought iron in contact with cast iron, the friction in rolling compared with that of sliding is as 63:2,000. The reason for using rolling friction as obtained in casters, wheels, and ball bearings is very evident.

Sliding Friction.—All surfaces are rough, differing only in the degree of roughness, and as one slides over the other the projections on one alternately fall into the cavities or rise over the humps of the other. As the smoothness of the surfaces is increased, the less rise and fall there will be and so the friction will be less.

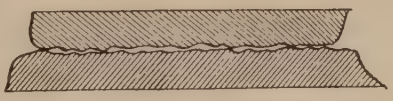


FIG. 14.—Sliding friction.

The friction between a shoe sliding over a cement floor is 0.9 lb. for each pound of pressure between the shoe and the floor. While the friction between a shoe and a waxed floor is only 0.3 lb. per pound of pressure.

Friction for solids is independent of the speed or the area of the moving bodies within wide limits. The friction between a solid and a liquid or a gas is not independent of the speed or the area. The air friction met by a rapidly moving automobile increases approximately as the cube of the velocity of the automobile; that is, if the automobile changes from 10 miles per hour to 30 miles per hour the air resistance is nine times greater. If one tries to double the speed of a row-

boat the greatly increased effort required is at once made evident.

Rolling Friction.—In rolling friction, the wheel as it moves forward compresses the part directly under it, thus making a little ridge ahead. The larger the wheel the less the compression, with a decrease in the friction. For example, nearly all iron beds have too small casters and require too much force to move them.

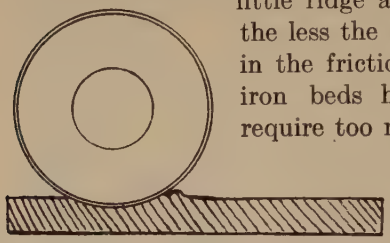


Fig. 15.—Rolling friction.

20. Coefficient of Friction. The force required to balance the force of friction between two bodies depends upon two factors: (*a*) the nature of the two surfaces in contact, (*b*) the *normal* or perpendicular force with which the bodies are pressed together.

The coefficient of friction is the ratio of the force required to move one body over another with uniform motion to the normal or perpendicular force between the surfaces.

$$\text{Coefficient of friction} = \frac{\text{force to balance friction}}{\text{normal force}}.$$

The coefficient of friction may also be defined as the fraction by which the force holding the bodies in contact must be multiplied to obtain the frictional force.

	Sliding Friction Coefficient
Steel on ice (skates)	0.32 to 0.16
Leather on waxed oak	0.20 to 0.35
Metal on metal	0.15 to 0.30
Wood on wood	0.25 to 0.50

	Rolling Friction
Steel on steel	0.007

21. Friction on Oiled or Lubricated Surfaces.—When the surfaces in contact are well oiled, the film of oil *lessens* the friction. Between metal surfaces it may not be more than $\frac{1}{6}$ or $\frac{1}{10}$ that of the same surfaces not oiled. The egg beater, the motor of the washing machine, the vacuum sweeper, the

sewing machine, and in fact all moving parts of the various household devices, should be given frequent oiling.

Illustrative Problems

1. What force will be required to pull a 75-lb. table over a floor if the coefficient of friction is 0.4.

$$0.4 = \frac{F}{75}, \text{ therefore } F = 30 \text{ lb.}$$

2. What force will be required to push a 100-lb. box up a certain plank if the coefficient of friction is 0.5? (see Fig. 13).

We must first find the normal force, that is, the component of the earth's pull on the box that acts perpendicular to the surface of the plank. This problem is evidently one in the resolution of a force as treated in **Art. 15.** The pull of the earth acts vertically downward, so let BW = this pull = 100 lb. = 1 in.

Complete the parallelogram, making BC normal or perpendicular to the plank. Then the length of BC on the scale of 1 in. representing 100 lb. will give the value of the normal force due to the box, $BC = 1\frac{5}{16}$ in. = 93.74 lb.

Then

$$0.5 = \frac{F}{93.74}, F = 46.87 \text{ lb.}$$

The force just found is simply the force required to overcome the friction. Had there been no friction it would still have required a force to push the box up the plank, for the earth's pull has a component parallel to the plank. This component is $AB = \frac{6}{16}$ in. = 37.5 lb. Hence the total force required to push the box is 37.5 + 46.87 = 84.37 lb.

The student should study this problem carefully, as it serves as an example of a common type of resolution of a force into two rectangular components.

3. To pull a 100-lb. bed along the floor requires a force of 20 lb.; what is the coefficient of friction?

$$\text{Coefficient} = \frac{20}{100} = 0.2.$$

Study Exercises

1. What is the force (pull) of the earth on yourself?
2. Find the force with which the earth tends to pull you *down* an inclined plane of length 20 ft. and height 10 ft.
3. The force acting on a carpet sweeper handle is 5 lb. Find the component of this force acting parallel to the floor when the handle makes an angle of 30 deg. with the floor.

4. A picture is hung from a nail by two equal wires. The angle at the nail between the wires is 45 deg. and the force at the nail (the weight of the picture) is 10 lb. Find the force in each wire.

5. What force will be required to pull a 50-lb. mass up an inclined plane of length 16 ft. and height 6 ft.? Friction is neglected.

6. On a given body two forces of 5 and 10 lb. act at an angle of 60 deg. to each other. Find the value of a single force, the resultant, which will be equivalent in its effect.

7. A baby cart, mass 30 lb., is first moving with a velocity of 2 ft. per second, but at the end of 4 sec. it has a velocity of 5 ft. per second. What force produced the change? Friction neglected.

8. A 120-lb. person running with a velocity of 7.5 miles per hour (11 ft. per second) has her motion stopped in one second by a wall. What force was exerted?

9. An automobile of mass 1,500 lb. had an acceleration of 5 ft. per second per second. What force produced this acceleration?

10. A 120-lb. person is ascending in an elevator the acceleration of which is 2 ft. per second per second. With what force is she pressing on the floor?

11. The force required to move a 75-lb. cedar chest over the floor, is 10 lb. What is the coefficient of friction? What force would be required to move a similar 125-lb. chest?

12. If the coefficient of friction of leather on waxed oak is 0.25, what force will be required to move a 150-lb. leather trunk?

13. A 50-lb. box is being pushed up a board 10 ft. long and 4 ft. high. The coefficient of friction is 0.2. What force is required to overcome the friction? Question, what is the normal force and how can it be found?

14. What force is required to push the box in Exercise 13 up the board with no friction? What is the total force required when friction is considered?

15. In a popular 10-cent novel the 120-lb. heroine was riding in a railway car equipped with the hero's wonderful quick-acting brakes. The train going 60 miles per hour was stopped in ½ sec. To what force was the heroine subjected?

16. On a horizontal surface a mass of 100-lb. is moved against a friction force of 10 lb. with an acceleration of 5 ft. per second. What force was required?

17. If the coefficient of friction between shoes and a waxed floor is 0.35, what force would be required to pull a 100-lb. person over such a floor?

18. If the friction between a silver spoon and the polishing cloth could be reduced one-half, would it be easier to clean the spoon?

19. Would an egg beater with very rough blades be better than one with smooth blades?

20. Is the friction between the iron and the garment desirable or not?

21. The rubber rolls on the wringer wear out rather quickly. Why not have rolls made of glass or enameled ware?

22. Why do knots stay tied?

23. Make a sketch showing the forces acting on a loaded bracket shelf.

24. Explain why a steady movement in sweeping is less tiresome than a changing motion, fast, then slow, or the reverse.

25. Why is a soft mattress more comfortable to sleep on than the harder mattress?

26. Why are not kitchen floors of tile or cement satisfactory?

27. Why does a quick shake of a small rug take out more dirt than a slow movement?

28. Why does a small rug on a polished floor sometimes cause one to slip?

29. Assume that a 120-lb. person in walking has a downward velocity of 5 ft. per second and that this velocity is changed to zero in $\frac{1}{5}$ sec. What is the force of the blow given to the body?

30. What force will be required to push a baby carriage, weight 40 lb., up a sidewalk which rises 20 ft. in a distance of 200 ft.? No friction.

Some Suggested Laboratory Exercises

1. A study of the forces in a wall shelf.
2. A study of the size of casters and the rolling friction.
3. The magnitude of the blow from a shoe with a rubber heel compared with that from a leather heel.
4. Experimental study of the effect of varying the angle of the handle of a carpet sweeper on the force which pushes the sweeper over the carpet.
5. Determination of coefficient of friction of leather on waxed oak.
6. The impact force of a leather heel on various floor coverings, also impact force due to a rubber heel.
7. Forces on a loaded clothes line. Load at different positions.

REVIEW SUMMARY

Primary idea of force from muscular effort.

Muscular effort not a quantitative measure of force.

Pound force the amount of the earth's pull on a pound mass.

Pound used as a unit of mass and a unit of force.

Stretch of a spring as a measure of the force and of mass.

Effect of a force depends upon its magnitude, direction, point where applied, time the force acts.

When forces are applied simultaneously to a body, the final effect is the same as if they were applied separately.

The result of adding two forces may be found from the diagonal of a parallelogram whose adjacent sides represent the two forces.

Any single force can be replaced by two forces.

Inertia—property of matter—resistance matter offers to a change in its motion.

Force can be measured by rate of change of momentum. Momentum is equal to a mass multiplied by a velocity.

This new unit of force is smaller than the pound force. To convert this new unit into pound or gram forces, the change of momentum must be divided by 32 or 980.

Acceleration is rate of change of velocity and force can be measured by *ma* which is equivalent to rate of change of momentum.

Friction is a resisting force. Useful and wasteful. Sliding friction in solids depends upon the nature of the surfaces in contact and the normal force between the surfaces. Friction between a solid and liquid or gas varies with the velocity.

Rolling friction is much less than sliding friction. Oiled surfaces have a decreased friction.

Coefficient of friction is the ratio between the force of friction and the normal force pressing the surfaces together.

CHAPTER III

ELASTICITY

22. Elasticity.—Bodies offer resistance to a change in volume, or shape, or both. Lord Kelvin defines elasticity as:

> . . . that property in virtue of which a body requires a force to change its bulk or shape, and requires a continuous application of the force to maintain the change, and springs back when the force is removed; and if left without the force, does not remain at rest except in its previous bulk and shape.

The criteria for high elasticity are: high resistance to distortion and complete return to the original state after the distorting force has been removed.

There are different ways in which a body may undergo distortion, to each of which belongs a different elasticity. There is elasticity of form, elasticity of volume, elasticity of bending, elasticity of compression and extension, elasticity of torsion or twisting. We shall confine our attention to elasticity of extension and of form.

23. Hooke's Law.—A perfectly elastic substance is not known, but Robert Hooke has stated the condition for assuming practical perfect elasticity. In 1678 he announced the law: "*Ut tensio sic vis*"; that is, the elongations produced are proportional to the forces applied.

The familiar spring balance is an illustration of the use of the law. If a given amount of sugar is hung on the spring, it will be stretched a certain amount, while twice the amount of sugar will stretch the spring twice as much.

24. Elastic Limit.—For every body there is a limit beyond which the proportionality between the elongations produced and the force applied no longer holds and the body does not return to its original condition when the force is removed. It has received a permanent set. Solids only have an elastic

limit. Liquids and gases can never receive a permanent set. From A to E the wire obeys Hooke's law. E marks the elastic limit. From E to B the stretch is no longer proportional to the force or load. At B the wire breaks. The load per unit area of the wire at this point is the tensile strength.

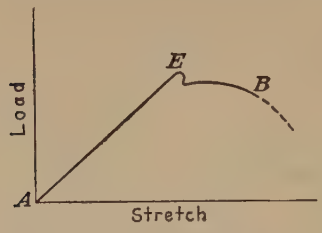


FIG. 16.—Relation between the load and the stretch of a wire.

In buildings the foundations and other supporting parts of the structure must never be subjected to forces of compression, elongation or bending of a magnitude sufficient to make the body approach its elastic limit. The table gives the elastic limit of some few materials used in building operations.

	Pounds per Square Inch
Structural steel	35,000
Wrought iron	25,000
Cast iron	6,000
Timber, general average	3,000
Concrete, compression	1,000
Stone, general	2,000
Brick	1,000

The familiar method of breaking a wire by repeatedly bending it beyond its elastic limit, shows how the resistance of a substance decreases when the elastic limit has been repeatedly exceeded.

25. Elastic Toughness or Extensibility.—The ability of a substance to be distorted through very wide ranges without exceeding the elastic limit is known as "elastic toughness" or "extensibility." This is an entirely different property from elasticity, although it is often confused with it. In popular usage, rubber is highly elastic, while steel is much less so. Rubber has a greater elastic toughness or extensibility than steel, but steel is the more elastic.

In many of the texts treating of the physical properties of fibers, the statements and data given under the topic "elastic-

ity" really refer not to the elasticity but to the extensibility, the total stretch up to the breaking point expressed in percentage or in fractions of an inch per foot of length. It is unfortunate that the word "elasticity" has been misused in this way.

26. Tensile Strength or Breaking Force.—After the elastic limit has been exceeded for a substance, the continued addition of a force causes an elongation of the substance out of proportion to the force applied, and it finally breaks (see Fig. 16). The force causing the rupture is called the breaking force and its magnitude per unit area is the tensile strength of the substance. Many writers on textiles call the tensile strength, breaking force, or breaking stress, the "breaking strain." This is an incorrect use of the word strain as used in mechanics. The tensile strength of some substances is given below:

Material	Tensile Strength in Pounds per Square Inch
Aluminum wire	40,000
Glass	2,400
Copper wire	45,000
Iron wire	56,000
Steel wire	224,000

27. Some Miscellaneous Properties of Solids.—In addition to elasticity, solids have many mechanical properties frequently mentioned, which are not yet defined with sufficient clearness to make it possible to measure them with any exactness. A few of these properties will be given here.

Malleability.—The property that permits a substance being hammered or rolled into thin sheets. Gold is the most malleable of all substances. A sheet 1 in. square and $\frac{1}{16}$ in. thick can be hammered into a sheet 125 in. square and 1/250,000 in. in thickness.

Ductility.—The property that permits the substance to be drawn out into thin wires. Silver and copper are very ductile; wires less than 1/1,000 in. in diameter are easily drawn. Heating substances that are not ordinarily ductile to a semi-

fluid state makes them so. Fine threads of glass and quartz are obtained in this way and everyone is familiar with the exceedingly fine threads obtained from sugar in boiling it down.

Plasticity.—The property that permits a substance to be molded. Beeswax and paraffin are highly plastic.

Hardness.—There are two uses of the word "hardness." One is the opposite of plasticity, the resistance to change of shape as when we call iron "hard" and rubber "soft." The mineralogist uses the word hardness to denote ability to scratch. The diamond is the hardest substance, scratching all others, and talc is the softest, being scratched by all others.

28. Some of the Physical Properties of Fibers.—In books treating of textiles, the physical properties of the fibers used in fabrics are given an important place because, in part, these properties determine the use that can be made of the fiber. We shall call attention to some of the physical properties of the more common fibers.

29. Cotton Fiber.—The cotton fiber (Fig. 17) has a ribbon-like form and is twisted so as to make an irregular spiral or screw-like band. The value of the fiber increases with the number of these spirals in a given length and with their regularity. No other bast fiber shows these twists and, hence, this characteristic identifies cotton at once.

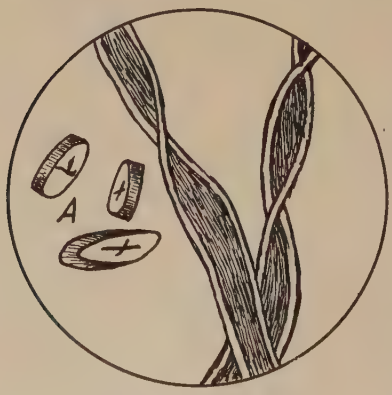


FIG. 17.—Cotton fiber.

The different varieties of cotton differ in the length of the fiber, in diameter, in elasticity and in tensile strength. The Sea Island cotton has the longest length, nearly 2 in., and the Indian cotton has the shortest length, 1 in. or less. The diameter in all the varieties decreases with increase of length. For the fiber having a ribbon-like form, not circular, the values given for its diameter are those obtained by measuring the greatest diameter of the oval

section of the fiber. The table gives some average data on the cotton fiber:

Variety	Length, inches	Diameter, maximum inches	Tensile strength		Stretch per unit length
			Grains	Grams	
Sea Island	1.61	0.00064	83.9	5.45	Less than either wool or silk
Egyptian	1.41	0.000655	127.2	7.26	
New Orleans	1.02	0.000775	147.7	9.61	
Indian	0.89	0.000844	163.7	10.64	

The breaking stress or tensile strength of cotton per square inch is about 47,000 lb. Compare with the metals.

When the fiber is made into yarn, the full strength of the individual fiber is not utilized. Single yarns have a strength of about 20 per cent of that calculated from the strength of the individual fibers. Two-ply yarns give about 25 per cent. In a 32's twist American yarn of 120 fibers, tensile strength of the fiber 140 gr., the tensile strength of the yarn was 49.5 lb., while the calculated strength was 200 lb., a loss of 73.3 per cent. Cotton is fairly plastic at 100°C. and can be pressed and molded into definite shapes. It is inferior in this respect to either wool or silk.

Moistening, hot drying, and then moistening again a cotton cloth does not produce any change in its strength.

The effect of bleaching on the strength of cotton threads has been studied by O'Neill and his conclusion is that the tensile strength of cotton threads is not only not decreased by the bleaching, but in most cases is actually increased. The wetting and pressure to which the threads are subjected probably cause a more perfect binding of the separate fibers.

When the cotton is immersed in a solution of caustic soda it undergoes a peculiar physical change. It swells to a cylindrical form. See (*A*) Fig. 17. It untwists itself and becomes shorter in length. These physical changes are accompanied by a great increase in its tensile strength, amounting to as much as from 30 to 50 per cent.

30. Wool Fiber.—The wool fiber is illustrated in Fig. 18. The different varieties of wool fiber vary in their physical properties even more than the cotton fibers. In length the fibers range from 1 to 8 in. and in diameter from 0.0018 to 0.004 in. The tensile strength and stretch vary with the breed and quality of the sheep, with the diameter of the fiber, and with the part of the fleece from which the wool is taken. The way in which these factors vary is shown by the table. The data on human hair is added for the sake of comparison.

Kinds of fiber	Diameter, inches	Tensile strength		Stretch in percentage of length
		Grains	Grams	
Human hair	0.00332	1641	106.3	36.6
Lincoln wool	0.00181	502	32.7	28.4
Australian merino	0.000517	50	3.3	33.5
Saxony merino	0.000338	39	2.5	27.2
Mohair	0.00170	586	37.9	29.9
Alpaca	0.000526	149	9.6	24.2

The elasticity of wool is shown when woolen garments, creased and wrinkled from being in a trunk, are hung up in the wardrobe. The disappearance of most of the wrinkles is due to the elasticity of the wool.

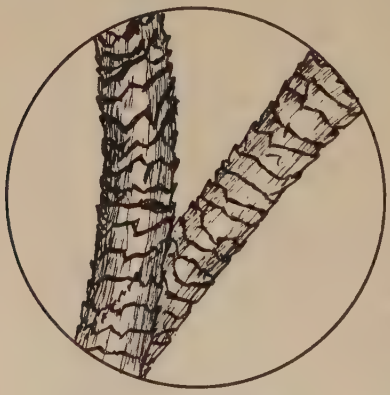


Fig. 18.—Wool fiber.

Wool at 100°C. is plastic, so it can be pressed and molded into various shapes which are retained when the wool cools. The wool fiber is much stronger than the cotton fiber, but comparing the tensile strength of the two for equal diameters, the tensile strength of wool is about 1,132 lb. per square inch, while that of cotton is 47,000 lb. The elastic limit is reached in wool when the total stretch

equals about 5 per cent of the original length of the fiber. This is about ten times greater than that for iron.

31. Silk Fiber.—An illustration of the silk fiber is shown in Fig. 19. The fiber is cylindrical in shape, smooth and transparent. The fibers range from 0.0005 to 0.001 in. The density of the silk fiber is the lowest among the textile fibers when it is degummed, and consequently light weight fabrics can be made from it. The strength of a fiber is from 4 to 5 g., which means a tensile strength of 64,000 lb. per square inch. The boiled off, degummed fiber loses about 30 per cent in strength. Its breaking stretch varies from 15 to 20 per cent of its length. Weighting the silk decreases both its strength and its elasticity.

FIG. 19.—Silk fiber.

Wet silk has a strength about one-half that of the dry silk. The strength returns with dryness. The high elasticity of silk is shown by crushing a silk garment in the hands. It returns readily to its original condition.

32. Flax or Linen Fiber.—The diameter of the fiber is from 0.0015 to 0.006 in. Its strength is greater than that of cotton. Its tensile strength is about 50,000 lb. per square inch.

33. Rayon.—The word "rayon" is given to certain synthetic fibers which are very extensively used in fabrics. Originally the fabrics were called "artificial silk," then "silk substitutes," because such fabrics have some of the properties of silk, and have somewhat the appearance of silk. Perhaps it is better to regard rayon fibers as an entirely new addition to the list of fibers used in fabrics.

Depending upon the method of production, rayon fibers may be divided into four classes; the nitrocellulose, the cupram-

monium, the viscose, the cellulose acetate. Commercially, these are known as Tubize, Bemberg, Rayon, and Celanese.

The appearance of these different fibers under the microscope enables the textile expert to readily distinguish the different types. The nitrocellulose fiber looks as if it were made of two or three rolls stuck together, thus forming one fiber. The cuprammonium fibers are very fine, looking much like the silk fiber except it is smoother. The viscose fiber shows longitudinal ridges making it appear rough. The cellulose-acetate fiber is the most difficult one to distinguish as it has somewhat the appearance of the cuprammonium and the nitrocellulose fibers.

Data on the elastic properties of rayon fibers similar to those given for the other textiles fibers do not seem to be available at the present time. The table below is accredited to the Bureau of Standards.

Fiber	Percentage stretch	Breaking strength Kg/mm^2	
		Dry	Wet
Viscose	20	21.5	3.5
Nitro	15.5		
Cupra	12	19.1	3.6

34. Metals and Fibers Compared:

Materials	Diameter in inches	Tensile strength in pounds per sq. in.	Stretch in inches per foot
Steel wire	0.001	0.175	0.089
Copper	0.001	0.035	0.31
Cotton (Sea Island)	0.00064	0.012	
Wool (Lincoln)	0.00181	0.072	3.40
Silk	0.0007	0.010	1.8
Flax	0.0035	0.45	
Rayon			
Human hair	0.0032	0.23	4.39

Study Exercises

1. A mohair fiber gave the following stretches for successive loads of ½ g. each: 11, 22, 33, 44, 55. Did Hooke's law hold?
2. The fiber in Exercise 1 after the total load was 2½ g. gave stretches for additional loads of ½ g., of 68, 82, 100, 120. Where did the fiber pass its elastic limit? Plot a curve with loads on the horizontal axis and stretches on the vertical axis for the data in Exercises 1 and 2.
3. What two physical changes in the fiber make a damp garment and a hot iron so effective in ironing?
4. Would you expect a spring balance to read differently for the same load under extreme temperature changes?
5. What property of pyrex ware makes it less easily broken by falls?
6. What reason have you for regarding hair as highly elastic?
7. Will woolen or cotton garments lose the more wrinkles by hanging in the closet? Why?

Suggestive Laboratory Exercises

1. Study of elastic properties of fibers.
   a. Breaking stress.
   b. Extensibility and elastic limit.
   c. Effect of temperature on (*a*) and (*b*).
   d. Effect of wetting and drying on (*a*) and (*b*).

REVIEW SUMMARY

Elasticity, that property of bodies by virtue of which they require a force to change their bulk or shape and a continuous force to maintain the change, and which when the force is removed, causes them to return to their original condition.

Hooke's law, the proportionality between force applied and stretch produced.

Elastic limit, the maximum load or force that can be applied while Hooke's law holds.

Elastic toughness or extensibility, the ability to be distorted through a wide range.

Tensile strength, the load per unit area at which the body is ruptured.

Elastic properties of the more common fibers.

CHAPTER IV

WORK—POWER—ENERGY

35. Work.—When a force acts on a body either to produce *motion* or to *change* its motion, the force is said to do work. Work is numerically equal to the product of the force and the *distance through which the force acts.* The distance through which a body moves is the same as that through which the force acts when the *direction* of the force and the body's motion are the same.

In the carpet sweeper illustrated in **Art. 14,** the direction of the force is parallel to the handle, while the movement of the sweeper is along the floor. To find the work done on the sweeper we use the f_2 component of F. But if S is the distance F moves when the sweeper has moved a distance s, then we can write, $FS = f_2 s$.

A 20-lb. vacuum sweeper, if lifted vertically 1 ft., requires the performance of 20 ft.-lb. of work. To move the sweeper along the carpet 1 ft. may require a force of only 2 lb., and the work done is then 2 ft.-lb. or only one-tenth the amount of work required to lift the sweeper vertically. The work required to move a body is always equal to the force times the distance moved. The mass or weight of the body is not in general equal to the force acting.

36. Work Units.—The foot-pound and the kilogram-meter are two common units of work. A foot-pound is the work done by a force of 1 lb. moving through 1 ft. Of course the two factors entering into work can be varied at will, and the amount of work remains the same as long as the *product* remains the same. A force of $\frac{1}{8}$ lb. moving through 8 ft. and a force of 8 lb. moving through $\frac{1}{8}$ ft. have performed equal amounts of work.

The amount of work being equal to the product of a force and a distance only, it is independent of the *time* required to

do the work. A 120-lb. woman climbs the stairs in 15 sec. and again in 30 sec. The amount of work in the two cases is the same.

37. Work in Walking.—In walking, the body is lifted at each step and work is therefore done. The factors upon which the amount of work performed depends are: the weight of the person, how high she raises her body as she walks and the length of her stride. One taking long strides or steps works more than when taking short steps. Her body falls farther in the middle of the long step (Fig. 20). The work done in walking is discussed also in **Art. 138.**

FIG. 20.—Walking; short and long steps.

38. Power or Activity.—While the amount of work done by a given force depends only upon the distance through which the force moves, nevertheless the *time* in which the work is done is important. Two persons may sweep the same carpet and do the same amount of work, but one may do the sweeping in 30 min. while the other requires 45 min. The *rate of doing work* is called "power" or "activity." The ordinary unit of power is the *horsepower*. An agent or force that is doing work at the rate of 33,000 ft.-lb. per min. or 550 ft.-lb. per second is working at the rate of 1 hp. It should be noticed that power does not indicate *how much work is done* but only the activity while the work is being performed. A 20-hp. engine can work at double the rate of a 10-hp. engine, but if the latter runs twice as long, the work done by each is the same. One housekeeper will do the housework in 3 hours that another would take 6 hours to do. The amount of work done is the same, but one is working at twice the rate of the other. Work done by the job usually makes the rate of doing work unimportant, but work paid for by the hour makes necessary a consideration of the activity of the worker.

A man working hard can work at about the rate of $\frac{1}{10}$ hp., while a woman can work at about $\frac{1}{15}$ hp. For short times one can work at a much greater rate. For example, a 120-lb. woman went up stairs in 5 sec. The stairs were 8 ft. high. She was working at the rate of 0.34 hp.

If the *amount* of work *done* is to be found when the rate is known, it can be determined by multiplying the *power* by the time. A $\frac{1}{4}$-hp. washing-machine motor, if run for 1 hour will have performed $\frac{1}{4} \times 33{,}000 \times 60$ ft.-lb. The horsepower-hour is a common unit of the amount of work done at a given activity and for a given time.

Illustrative Problems

1. If a 120-lb. woman ascends the stairs to a vertical height of 10 ft., how much work does she perform? If her time of climbing was 5 sec. at what horsepower was she working?

$$\text{Work} = F \times S.$$
$$120 \times 10 = 1{,}200 \text{ ft.-lb.}$$
$$\text{Hp.} = \frac{\text{work}}{550 \times \text{time in seconds}} = \frac{1{,}200}{550 \times 5} = 0.43.$$

2. In wringing a garment the force on the wringer handle was 8 lb. The hand moved ten times through a circle of circumference 3 ft. What work was done?

$$W = F \times S$$
$$= 8 \times 3 \times 10 = 240 \text{ ft.-lb.}$$

3. In emptying a washtub a 10-qt. pail was filled five times and lifted vertically a distance of 2.5 ft. If 1 qt. of water weighs 2 lb., the work done was $10 \times 2 \times 2.5 \times 5 = 250$ ft.-lb.

4. A certain sewing machine required a force of 4 lb. on the heel side of the treadle in doing a piece of sewing. The heel side of the treadle moved 2.75 in. for each movement. How much work was done during 500 heel movements?

$$W = F \times S.$$
$$500 \times 4 \times 2.75 \times \tfrac{1}{12} = 458.3 \text{ ft.-lb.}$$

5. A washing-machine motor is rated as $\frac{1}{4}$ hp. How much work can be done in 1 min.?

$$0.25 \text{ hp.} = \frac{\text{work done}}{33{,}000 \times 1 \text{ min.}}. \quad \text{Work done} = 8{,}250 \text{ ft.-lb.}$$

6. A 20-lb. floor-wax polisher is pushed a distance of 5 ft. at each stroke, the coefficient of friction being 0.4. What work is done per stroke?

$$0.4 = \frac{\text{friction force}}{\text{normal force} = 20}. \quad \text{Friction force} = 8 \text{ lb.}$$

Then

$$W = 8 \times 5 = 40 \text{ ft.-lb.}$$

7. A 10-lb. box is being pushed up the incline illustrated in Fig. 13 with an acceleration of 2 ft. per second per second. The coefficient of friction is 0.1. How much work is required to move the box 10 ft.?

$$0.1 = \frac{\text{friction force}}{\text{normal force} = BC = 9.43}. \quad \text{Friction force} = 0.94 \text{ lb.}$$

Force required to produce the acceleration is

$$F = \frac{10 \times 2}{32} = 0.625 \text{ lb.}$$

Pull of earth along the incline $= AB = 3.33$ lb.
Total force required is $0.94 + 0.625 + 3.33 = 4.895$ lb.

$$W = 4.895 \times 10 = 48.95 \text{ ft.-lb.}$$

8. A ¼-hp. washing-machine motor worked for ½ hour. How much work was performed?

$$W = \tfrac{1}{4} \times 33{,}000 \times 30 = 247{,}500 \text{ ft.-lb.}$$

39. Energy.—We shall find as we continue our study of physics that a body may be able to do work because of:

(*a*) Its position—a waterfall.
(*b*) Its speed—balance wheel on a sewing machine.
(*c*) Its temperature—expansion of substances.
(*d*) Its electrical condition—vacuum-cleaner motor.
(*e*) Its chemical composition—baking powder.

This ability to do work is called "energy." The work which a system or a body can do is the measure of its energy, and the units for measuring energy are, therefore, the same as the work units.

40. Kinetic and Potential Energy.—In mechanics we limit our study of energy to (*a*) and (*b*) in the above list.

The uncoiled watch spring will not run the watch, but when, by winding, the relative position of its parts is changed, the watch will run, due to the energy which was put into the coiled spring. Energy which a body possesses by virtue of its position is called "potential energy."

The rapidly falling hammer drives the nail into the wood. The energy of the moving hammer does work in forcing the nail into the wood. The *revolving* wheel on the sewing machine drives the machine. The energy which a body possesses by virtue of its speed is called "kinetic energy."

41. Potential Energy Measured.—How shall we measure the energy of the coiled watch spring, of the water in the attic tank, of the book resting on the table?

Experiment shows that the work done in coiling the spring, in putting the water into the tank, and in placing the book on the table, is, neglecting frictional losses, exactly equal to the potential energy now in the body. If 100 lb. of water are in the tank which is 30 ft. above the basement, then the work done in filling the tank is 100×30 ft.-lb., and this is its potential energy. An 8-oz. book was raised 30 in. and the work done was $(\frac{1}{2} \times 2.5)$ ft.-lbs. Its potential energy is 1.25 ft.-lb.

42. Kinetic Energy Measured.—In giving the wheel of a sewing machine a speed of 3 ft. per second, a force of 4 lb. on the treadle moved through 0.46 ft. Neglecting friction, the work done on the wheel in giving it motion was $(4 \times 0.46) = 1.84$ ft.-lb. This is then the kinetic energy of the wheel. It is usually more convenient to measure the kinetic energy of a moving body in terms of its mass and speed.

Let a force F act on a body at rest. The body will have a uniformly accelerated motion. The force will produce an acceleration which can be found from the equation:

$$F = \frac{ma}{32}. \tag{1}$$

If the body starts from rest, zero velocity, its velocity at the end of t seconds is obtained from:

$$v = at \text{ (Art. 17)}. \tag{2}$$

It may be shown that the distance a body will go in t seconds with uniformly accelerated motion can be found from the equation:

$$S = \tfrac{1}{2}at^2. \tag{3}$$

Equation (1) gives a value for the force acting, and equation (3) for the distance the force moved while acting on the body. Hence we have the factors for finding the work performed. Multiply equations (1) and (3) member by member:

$$F \times S = \frac{ma}{32} \times \frac{1}{2}at^2 = \frac{ma^2t^2}{2 \times 32}.$$

From equation (2)

$$a^2t^2 = v^2.$$

Hence

$$F \times S = \frac{mv^2}{2 \times 32} = \text{foot-pounds} = \text{kinetic energy}.$$

The sewing machine wheel (**Art. 42**) has a mass of 13.08 lb. and a velocity of 3 ft. per sec. The kinetic energy of the wheel was then:

$$\frac{13.08 \times 3^2}{2 \times 32} = 1.84 \text{ ft.-lb.}$$

The fan in a vacuum sweeper had a mass of ¼ lb. and was revolving at a speed of 60 ft. per second. Its kinetic energy was:

$$\frac{0.25 \times 60^2}{2 \times 32} = 14.09 \text{ ft.-lb.}$$

43. Energy Transformation—Concrete Illustration.—

Mechanical to thermal	heat produced by friction.
Mechanical to electrical	dynamo or static machine.
Mechanical to chemical	setting off, by a blow, of a detonating compound.
Electrical to mechanical	motor.
Electrical to thermal	heating of wire by a current.
Electrical to chemical	electrolysis.
Chemical to mechanical	life processes.
Chemical to electrical	primary cells.
Chemical to thermal	animal heat—combustion.
Thermal to mechanical	expansion of a body.
	steam engine.
Thermal to electrical	thermo-pile.
Thermal to chemical	growth of vegetation.

44. Conservation of Energy.—Throughout all the various transformations of energy, it is found that no body or system of bodies ever acquires energy save at the expense of the energy

possessed by some other system. The amount of energy lost by one system is the exact equivalent of that gained by the other system. It follows that no machine or system of machines can be made to give out *more* energy than is given to it.

Machines cannot even return in useful work the energy they receive. There are unavoidable wastes due to friction which comes from a transformation of some of the received energy into heat. This energy is not available for doing work. It is not lost but transformed. There is no evidence that any energy has ever been annihilated. Like matter, it can neither be created nor destroyed.

The law of the conservation of energy expresses the fact that the energy in any isolated system remains the same. The fuller meaning of this law will be more evident after the study of heat has been taken up.

45. Laundry Machines.—A good example of the drudgery of house work is in the use of the washboard. A comparison of the work done in rubbing in a family wash with that of any other household task would show clearly that it stands first.

The mechanical washer as a household device is nearly unique in one respect: it is the greatest of work savers, as its use entirely replaces hand labor. Rubbing is in its nature entirely mechanical and so should be done mechanically.

The physical principle in all washing devices, whether hand or machine, is friction. By rubbing or by giving some type of motion to clothes or water, or both, the dirt is loosened and the suds are forced through the fabric, carrying the dirt away.

There are at present nearly 150 different makes of washing machines manufactured. Many of them are highly efficient, some are good and some are not to be considered from any standpoint.

46. Types of Machines.—The various makes may, with a few exceptions, be classified under one of three types:

1. *The Cylinder Type.*—In this type there is an outer and an inner drum of wood or metal. The inner drum is perforated and has shelves which give a motion up and down to the clothes as the drum revolves. The action is reversed

after a few revolutions and the water is thus forced through the clothes.

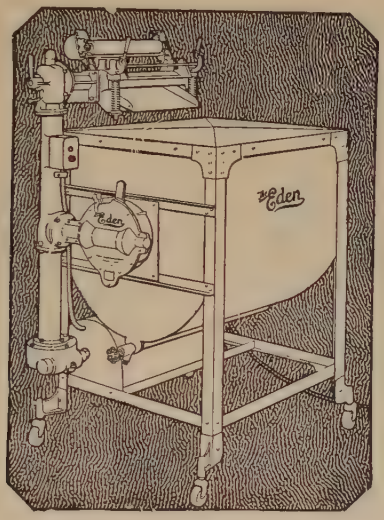


Fig. 21.—Cylinder type.

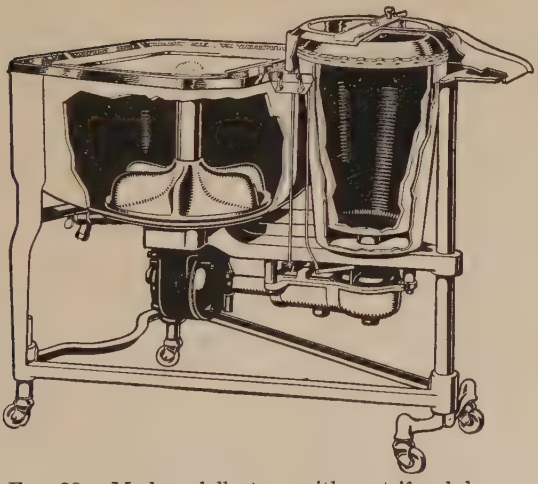


Fig. 22.—Modern dolly type with centrifugal dryer.

2. *Modern Dolly Type.*—The inverted dolly or agitator rotates in the tub, giving a gentle washing action. The

clothes circulate from the center of the tub to the sides, down and up under again. An auxilliary centrifugal or spinning dryer throws the water to the outside wall and upward, where it escapes through small openings in the top plate.

3. *The Vacuum Type.*—The clothes are washed in this type by the pressure and suction produced by one or more metal cones which alternately press and release the clothes.

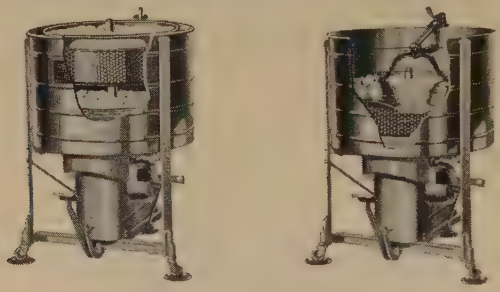


FIG. 23.—Vacuum type.

The machine which is *best* is largely independent of the type, but depends upon many factors, not the least of which is how it is used. Any one of the types may be used so as to be equally harmless on the clothes.

In the electric washers the motor should be located in such a position that there is little danger of its getting wet. The washer with enclosed gearing will generally give less trouble than one with belts which must be tightened. Metal tubs of copper, tin lined or nickel alloy will give longer service than the wooden tubs.

47. The Dryer.—Electric wringers are a part of nearly all types of electric washers. The reversible wringer and a good type of swinging wringer is to be preferred to the stationary type. It is important that the wringer have an emergency cut-off so it may be stopped easily if fingers or clothes are caught.

In some washing machines, the clothes are dried by being placed in a rapidly rotating perforated cylinder, the water being thrown out of the clothes by the whirling action. This type of washer produces better drying in less time, saves

wear and tear on the clothes and the buttons, and removes the possible danger of a caught finger.

Study Exercises

Work—Power—Energy.

1. A wringer with an 8-in. handle requires a force of 10 lb. on the handle to wring out a garment. The handle made four complete revolutions. Find the work performed. Friction neglected.

2. A 100-lb. girl walks up a stairway 9 ft. high in 10 sec. How much work does she do? At what horsepower was she working? If she made the same ascent in 3½ sec., find the work done and the rate of working.

3. Assume that a 120-lb. woman, 5.5 ft. high raises her mass one-thirtieth of her height at each step and that her steps are 20 in. long. Find the work she does in walking 1 mile in doing her housework.

4. A carpet sweeper is pushed with a force of 6 lb. in the horizontal direction. One hundred 30-in. strokes are made in sweeping. Find the work done.

5. Does the right or the left hand work the more in sweeping?

6. Will more work be done in walking over a bare or over a carpeted floor?

7. The work per second in running a given sewing machine was 19,000 g.-cm. What was the rate of doing work in horsepower? If this is an average machine, will a $\frac{1}{16}$-hp. motor be a satisfactory motor for sewing machines?

8. A small water motor for sharpening knives, etc., receives 2 lb. of water per second moving with a velocity of 20 ft. per second. What amount of energy does it receive per second? What is its horsepower?

9. How is the energy transformed in striking a match?

10. If the average force in sweeping a rug is 3 lb., and 100 strokes 18 in. long are made, how much energy was expended? One ounce of dirt was moved 5 ft. What part of the energy was used in moving it? How was the rest of the energy used?

11. A quart of water weighs 2 lb. If you fill a 10-qt. pail five times in emptying a washtub, and lift it 30 in., how much work do you perform?

12. The coefficient of friction of a set of bed casters is 0.05. What work is done in moving a 150-lb. bed 3 feet?

13. In turning the handle of a bread mixer a force of 3 lb. was exerted. The handle was 10 in. long and made 30 revolutions per minute. What was the work done and the rate of doing work?

14. In screwing on the cover of a fruit jar, a force of 10 lb. was used to tighten the cover, which moved ½ in. What was the work done?

15. A ¼-hp. water motor was to be used in a home where the water system could deliver 12 lb. of water per second at a velocity of 30 ft. per second. Neglecting friction losses, could the motor be operated?

16. A 100-lb. mass is raised vertically a distance of 10 ft. What was the force required? How much work was done?

17. The mass in Exercise 16 was pushed up an inclined plane, length 20 ft., height 10 ft., no friction, for a distance of 10 ft. What force was required?

18. The same conditions as in Exercise 17 except that the coefficient of friction was 0.1. What force was required to overcome friction? What was the total force exerted to move the body? What was the work done?

19. The same conditions as in Exercise 16 except that the mass had an acceleration of 4 ft. per second. What force was required to produce the acceleration? What was the total force acting? How much work was done?

20. A 100-lb. mass is pushed up an inclined plane, length 20 ft., height 10 ft. The force of friction is 10 lb. and the mass has an acceleration of 4 ft. per second per second. What was the total force acting? What work was done when the mass moved 10 ft.?

21. Find the work done in Exercise 20 if the mass had been raised vertically the height of the plane.

22. A 120-lb. person ran up a stairs of vertical height 9 ft. What was the work done?

23. If in Exercise 22 the work was performed in 4 sec., at what rate in horsepower did the person work?

24. An automobile engine is 30 hp. How much work can it do in 30 sec.?

25. A sewing machine may do 1.25 ft.-lb. of work per second. At what horsepower is it working?

26. The water in an attic tank is at an average height of 20 ft. above the basement floor. The tank holds 150 gal. (1,200 lb.) of water. How much work was performed in pumping the water? What is the potential energy of the water?

27. To wind the spring of a $2 watch required a force of 10 g. moving through 150 cm. What was the potential energy of the spring?

28. A 120-lb. person is running at the rate of 5 miles per hour (7.3 ft. per second). What is her kinetic energy?

29. A 2,500-lb. automobile moving at 45 miles per hour (66 ft. per second) has what ability to do work?

30. On a straight and level paved road it has been found that the force required to keep an automobile moving at 20 miles per hour is, on the average, 4 per cent of its weight. What must be the useful horsepower of a 2,500-lb. automobile to keep it moving at that speed. Assuming this as a satisfactory speed at all times, can you see any reason why the horsepower of the engine should always be greater than that just found?

Some Suggested Laboratory Exercises

1. The amount of work done in walking during a laboratory period, using a pedometer.

2. Work done in sewing under fixed conditions.

3. The horsepower used in Exercise 2.
4. The work performed in using some household appliances.
5. Find the amount of work you do and your rate of working when going up the stairs (*a*) usual speed, (*b*) as fast as you can.

REVIEW SUMMARY

Work, the result of a force acting through a distance.

Direction of movement of the force and of the body on which the force acts must be the same.

Foot-pound, the work done by a force of 1 lb. moving through 1 ft.

Power or activity, the rate of doing work.

Horse-power, the work being done at the rate of 33,000 ft.-lb. per minute or 550 ft.-lb. per second.

Power multiplied by time of working gives amount of work done

Energy, ability to do work.

Potential energy, the energy of position, measured by work done.

Kinetic energy, ability to do work by virtue of a body's motion. Measured by $\frac{mv^2}{2 \times 32}$ ft.-lb.

Transformations of energy.

Conservation of energy, no energy lost but transformed from one type into another type.

Laundry machines, washers by friction.

Three types, cylinder, oscillating or rocking, and vacuum.

CHAPTER V

MACHINES

48. Machines.—A machine is a device for transferring work from one point to another. The *advantage* of a machine consists in the ability to *control* the *two factors* that enter into work, *force* and *distance*. By the aid of a machine, a small force acting through a great distance may be able to replace a large force moving through a small distance. A machine may multiply enormously the force applied but can never increase the work done. The work done *on* the machine is equal to the work done *by* the machine. This statement holds only for an ideal machine. All real machines have friction, and the *useful* work done is always less than the work performed on the machine. The ratio of the useful work *done by* the machine to the work performed *on* the machine is known as the *efficiency* of the machine.

The *mechanical advantage* of a machine is the ratio of resisting force F_r to the working force F_w. This ratio $\frac{F_r}{F_w}$ is usually most easily determined in terms of some dimensions of the machine. The *speed advantage* is the reciprocal of the mechanical advantage.

All machines are essentially combinations of one or more of the so-called "mechanical powers." These are the lever, the wheel and axle, the inclined plane, the screw, the wedge, and the pulley.

49. The Lever as a Machine.—A lever consists of a bar free to rotate about an axis called the fulcrum. When a force F_w is applied at one end of the bar, the force moves through a certain distance S and does work on the lever equal to F_wS. The lever transfers this work to the other end where a resistance F_r is overcome, or, a body is moved through a

distance s and work is done equal to $F_r s$. In the figure, F_w and F_r are, respectively, the working force and the resisting force and o is the fulcrum.

FIG. 24.—The lever.

In **Art. 48** an ideal lever would permit the relation $F_w S = F_r s$. The work done *on* equals the work done *by* the lever. The efficiency of this lever would be 100 per cent or the ratio would be 1 for an ideal lever but always less than 1 for any actual lever. The mechanical advantage of the lever would be F_r/F_w. This ratio, as can be seen from the relation $F_w S = F_r s$, is equal to S/s, and since the two triangles with apex at O are similar, $S/s = L_r/L_w$. In this case the mechanical advantage of the lever is most easily found from the ratio of the lever arms L_w and L_r. For the lever, then, the mechanical advantage which is always F_r/F_w can be stated to be the *inverse* ratio of the lever arms. The speed advantage is equal to F_w/F_r, that is, the reciprocal of the mechanical advantage.

50. Three Classes of Levers.—The location of the working force and the resisting force with respect to the fulcrum determines the class of the lever.

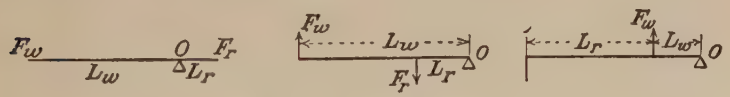


FIG. 25.—Classes of levers.

In levers of the first class, the fulcrum is *between* the working force and the resisting force and the F_w lever arm L_w is longer than the F_r lever arm L_r. The mechanical advantage is greater than 1.

In levers of the second class the *only* difference is in the position of the fulcrum with respect to the forces acting.

In levers of the third class, the working force arm is *shorter*

than the resisting force arm, so the ratio of F_r/F_w is less than 1. In this case there is a speed advantage, F_r moving at a greater speed than F_w. The forearm and the fingers are good illustrations of levers of this class and the swiftness which results gives the hand its great dexterity.

The illustrations show some common types of levers.

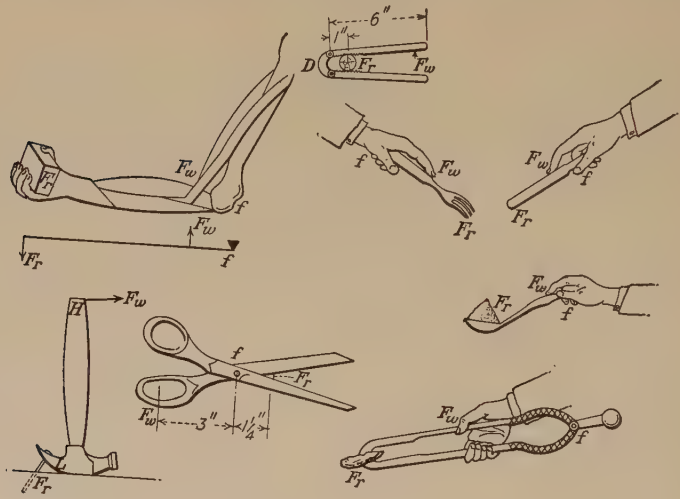


Fig. 26.—Some illustrations of the applications of the lever.

Illustrative Exercises

1. A nut cracker is a second-class lever. If the working force is 2 lb., the working force arm 6 in., and the resisting force arm 1 in., what force can be applied to crack a nut?

$$\frac{F_r}{F_w} = \text{inverse raito of the arms} = \frac{6}{1}.$$

The mechanical advantage of this lever is 6, that is, the resisting force is six times that of the working force, or 12 lb.

2. It is desired to raise a mass of 1,000 lb. by means of a lever of the first class with a working force of only 50 lb. What must be the relative lengths of the lever arms?

Since F_r/F_w is 1,000/50 the mechanical advantage must be 20. Hence, the ratio of working-force arm to resisting-force arm must be as 20 is to 1. If then, the working-force arm is made 10 ft. the resisting-force arm must be ½ ft.

51. The Wheel and Axle or Crank and Axle.—The illustrations show the essential parts of this type of machine. To find the mechanical advantage, we use the work equation for an ideal machine. The work done by F_w is equal to F_w times the distance it moves in one complete revolution of the wheel or the crank, that is $F_w \times 2\pi R$, where R is the radius of the wheel or crank. The work done by F_r is F_r times the distance it moves in one complete revolution of the axle, or $F_r \times 2\pi r$ where r is the radius of the axle. Hence $F_r/F_w = R/r$. The mechanical advantage of this type of machine is equal then to the inverse ratio of the radii of wheel or crank and the axle:

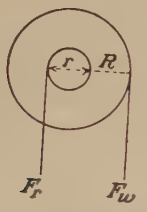


FIG. 27.—Wheel and axle.

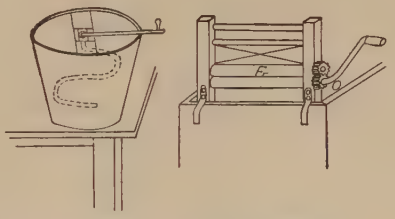


FIG. 28.—Crank and axle.

52. Pulleys.—In pulleys of the type represented by Fig. 29(a), the mechanical advantage is zero for it is evident that the distance moved through by the working force F_w is the *same* as the distance moved through by the resisting force. The only advantage is that of a more convenient direction of action for the working force.

Figure 29(b) represents a type known as the single movable pulley. When the working force F_w has moved a distance S, the resisting force F_r and the movable pulley B have moved through a distance of one half S, since each of the supporting cords for B have been shortened only one-half as much as the cord for F_w was lengthened.

The mechanical advantage of a single movable pulley is then 2.

Another combination of pulleys consists of movable and fixed pulleys with a continuous cord, Fig. 29(c). This evidently is an arrangement similar to the case just discussed. The

mechanical advantage is 6. In both these cases, the mechanical advantage can be stated as being equal to the number of supporting cords or as equal to twice the number of movable pulleys.

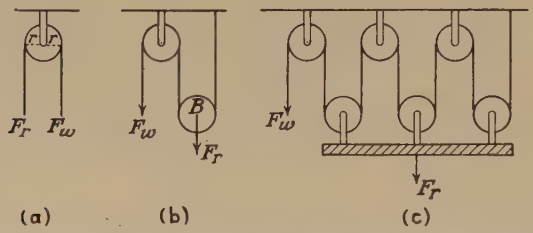


FIG. 29.—(*a*) Single fixed pulley. (*b*) One fixed, one movable pulley. (*c*) System of fixed and movable pulleys.

53. The Inclined Plane.—In the inclined plane the working force F_w is usually moving parallel to the incline, while the resisting force F_r, due to the earth's pull, is acting vertically. The work done by the two forces when the body is at the top of the incline is F_wL and F_rh (Fig. 30). Neglecting friction, the mechanical advantage of the plane is therefore $F_r/F_w = L/h$, or the ratio of the length of the incline to the height.

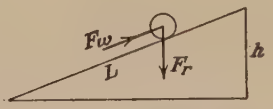


FIG. 30.—Inclined plane.

54. The Screw.—The screw is generally combined with a lever arm and the simplest method of finding the mechanical advantage is to find the work relations. If the pitch of the screw be denoted by s, the lever arm by l, then in one complete revolution of F_w, the resisting force F_r moves vertically a distance s and

$$F_w \times 2\pi l = F_r s.$$

Hence

$$\frac{F_r}{F_w} = \frac{2\pi l}{s},$$

or the mechanical advantage of the screw equals the ratio of distance traveled by F_w in one complete revolution of the screw to the pitch of the screw.

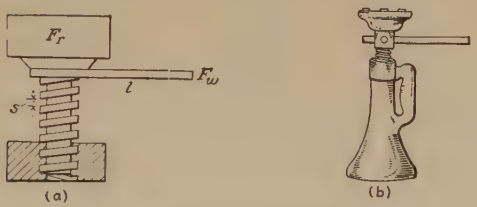


FIG. 31.—The screw.

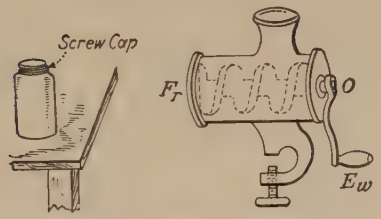


FIG. 32.—Screw applications.

Illustrative Exercises

1. A can opener of the lever type has a resisting force arm ¾ in. long and a working force arm 5 in. long. What resistance is being overcome when a force of 2 lb. is applied?

$$\frac{F_r}{2} = \frac{5}{\frac{3}{4}},\ F_r = 13.3 \text{ lb.}$$

2. A cube of sugar weighs 6 g. Sugar tongs with a resisting force arm 5 in. and a working force arm 4 in. are used to pick up the sugar. What is the working force? What type of lever?

$$\frac{6}{F_w} = \frac{4}{5},\ F_w = 7.5\ g. \text{ (third-class lever).}$$

The mechanical advantage is less than one but the speed advantage is the reciprocal of this, or $\frac{1}{\frac{4}{5}} = 1.25$. The speed advantage is more useful than a decrease in the force applied.

3. A bread-mixer handle is 10 in. long and the mixer bar has a radius of 3 in. What is the resisting force in mixing the dough when a force of 4 lb. acts on the handle?

The mixer is a type of crank and axle, hence

$$\frac{F_r}{4} = \frac{10}{3},\ F_r = 13.3 \text{ lb.}$$

4. A wrench 8 in. long is used to loosen an iron screw whose threads have a pitch of $\frac{1}{16}$ in. The rusted screw offers a resistance of 320 lb. to being turned. What force must be used?

$$\frac{320}{F_w} = \frac{2\pi \times 8}{\frac{1}{16}}, \quad F_w = 0.39 \text{ lb.}$$

Study Exercises

1. What is the mechanical advantage of a lever whose working force arm is 100 cm. long and whose resisting force arm is 10 cm. long?
2. What resistance can be overcome by the lever in Exercise (1) when the force applied is 15 lb.?
3. A lever with a working force arm of 15 cm. and a resisting force arm of 75 cm. has what mechanical advantage? What class lever is it? What is the speed advantage?
4. The force on the toe side of a sewing machine treadle is 8 lb. and the force on the heel side is 4 lb. What is the mechanical advantage? Is it possible to have two answers from the statement of the problem?
5. A wheel of radius 10 cm. and an axle of 4 cm. radius will give what mechanical advantage?
6. If the mechanical advantage of the wringer is 8, what is the ratio of handle radius to the wringer roller radius?
7. A screwdriver may be considered as a type of wheel and axle. If the diameter of the handle is $1\frac{1}{2}$ in. and the diameter of the blade is $\frac{1}{4}$ in., what force can be exerted on a screw when the force at the handle is 3 lb.?
8. In an egg beater the force on the handle arm is 1 lb. and the resisting force is 4 lb. What is the mechanical advantage?
9. In a system of fixed and movable pulleys with a continuous cord, there are six supporting cords. What mass can be lifted when the applied force is 20 lb.?
10. A stairs is 20 ft. long and 8 ft. high. If a 120-lb. person ascends, what force is exerted? What is the mechanical advantage of the stairs?
11. To push a 200-lb. barrel from the basement, 7 ft. below the ground, with a force of 50 lb., what length plank would be needed?
12. The screw in a meat chopper has a pitch of $1\frac{1}{4}$ in. The length of the handle is 8 in. What is the mechanical advantage of the machine? If a 4-lb. force is used at the handle, what resistance can be overcome?
13. In an actual machine the work done on the machine was 12 ft.-lb. and the work done by the machine was 9 ft.-lb. What is the efficiency of the machine?
14. What class of lever is the foot when we rise on the toes?
15. Locate the points of application of the force, the weight and the fulcrum in a broom, a shovel, and a door.
16. Explain what is meant by saying a machine makes it "easier" to do work.

17. In the egg beater is the advantage one of speed?

18. A nut cracker has a force arm 6 in. long and the nut is placed 2 in. from the hinge. If the nut requires a force of 16 lb. to crack it, what force must be exerted?

19. A wringer roll is 1½ in. in radius and the handle 12 in. in radius. If the hand exerts a force of 8 lb., what is the force driving the clothes between the rolls? Friction is neglected.

20. In a meat grinder, the handle arm is 8.5 in. and the average pitch of the screw is ¾ in. If the resistance is 10 lb., what force must be exerted? Friction is neglected.

21. The diameter of a can cover is 3 in. and the pitch of the screw is ¼ in. What force can be exerted on the top of the can to unscrew it by a force of 10 lb.?

22. In an equal-arm balance, one arm is found to be 8 in. long and the other arm 8.1 in. long. What error will be introduced? Two solutions.

23. What is the advantage of a pair of stairs over a vertical ladder?

24. What is the mechanical advantage of the wheels connected by the belt on the sewing machine?

25. In a given machine, the average force on the treadle was 13.5 lb., the force moved through a distance of 1 in. The needle exerted a force of 5.5 lb. through 1.75 in. What was the efficiency of the machine?

26. Study a sewing machine and point out the simple machines, lever, pulley, etc., wherever they are used.

27. What is the advantage of ball bearings?

28. What is the mechanical advantage of a bread mixer?

29. Why are machines oiled?

30. In the family-size ice cream freezer, what is the purpose of the cog wheels?

31. Determine what differences would be produced by doubling the diameter of the drive wheel on an egg-beater.

55. The Mechanics of the Sewing Machine.—The sewing machine, which has been called "America's chief contribution to civilization," had its beginning in 1846 when Elias Howe of Massachusetts received the first patent. In 1851, Isaac Merritt Singer patented his first machine, and during the years that have followed, many persons have contributed to making the sewing machine what it is today, a nearly perfect adaptation to the purposes of sewing of the simple machines already discussed.

The data used in this discussion are taken from the study of one machine, but are representative of all machines.

56. The Treadle.—The treadle is alternately a lever of the first and third class as the working force (the force exerted by

the foot) is changed from the toe to the heel. The combined toe and heel forces, moving through distances for a certain machine of $1\frac{7}{8}$ and $2\frac{3}{4}$ in., respectively, furnishes the work for running the machine.

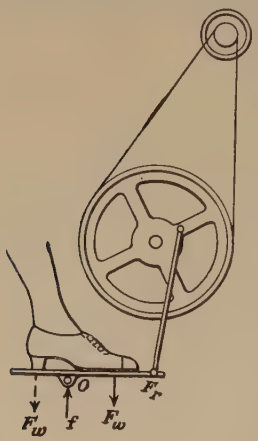


FIG. 33.—The treadle.

The band wheel makes one complete revolution for each complete up and down movement of the heel side of the treadle.

57. The Band Wheel.—The band wheel and axle below the platform are a combination formed by the large band wheel and its iron projection to which the treadle rod is attached. Since the axle force moves through a smaller distance than the band-wheel resistance, the relative radii of the axle and the band wheel for the machine used being 1:4, the mechanical advantage is $\frac{1}{4}$, a loss in the magnitude of resistance or force exerted by the band wheel. The reciprocal of the mechanical advantage is the speed advantage, in this case equal to 4. A point on the circumference of the band wheel moves through four times the distance in one complete revolution that a point on the circumference of the axle moves through.

58. The Band and Balance Wheels.—The work done by the treadle is transmitted to the band wheel by means of the belt. The efficiency of the transmission depends upon the tightness of the belt. There must be developed as much friction as possible between the belt and the wheel while keeping the friction between the wheel axle and its bearing small. It may be shown also that the efficiency of transmission varies with the length of the arc over which the belt makes contact with the wheel. But as this condition is fixed by the makers,

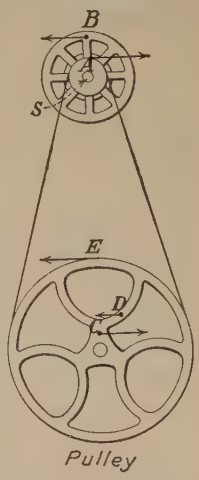


FIG. 34.—Combination of pulleys.

the only variable under the control of the operator is the belt tightness.

The band and balance wheel with the belt forms a pulley combination. The work done by the band wheel on the balance wheel may easily be found by wrapping a cord around the band wheel and by pulling at *E* with a spring balance. A cord was wrapped around *A* and a spring balance attached to it. A pull of 600 g. on *E* through a distance equal to the circum-

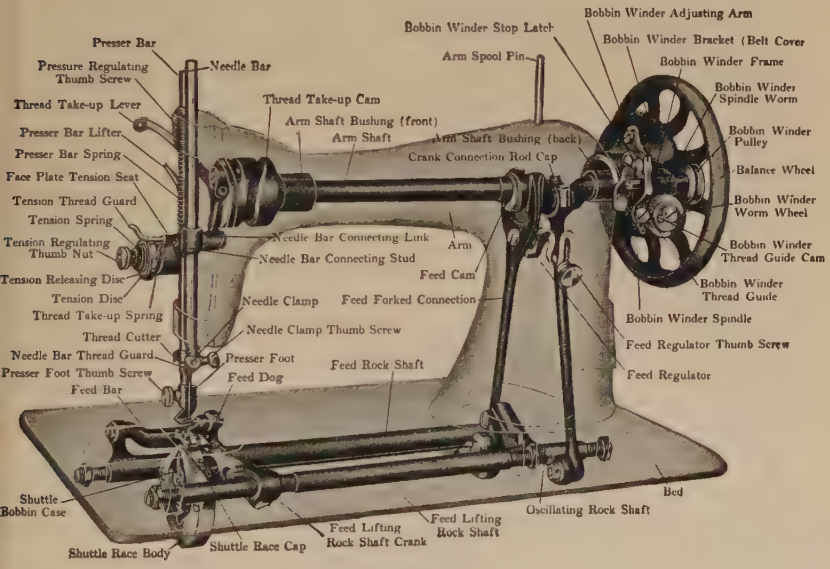


FIG. 35.

ference of the wheel gave a reading of approximately 2,400 g. at *A*, and the distance moved was one-fourth the *E* distance. In other words, the work done on the band wheel was approximately equal to the work done on the balance wheel. The mechanical advantage was 4, the radii of the belt wheel and band wheel being as 4:1.

The work done on the balance wheel is transmitted to the needle, the bobbin and the feeder by wheel-and-axle combinations as shown in the figure.

59. Relative Movements of Some Parts.—

1. The treadle makes one complete heel movement while the band wheel makes a complete revolution; the circumference of the band wheel being 38.5 in. and the movement of the heel side of the treadle being 5.5 in., the speed ratio is $38.5 \div 5.5 = 7$.

2. The speed ratio of the balance wheel to the band wheel is as 4:1.

3. The needle makes one complete movement for each revolution of the balance wheel, or four complete movements for one revolution of the band wheel.

4. The needle, therefore, makes four complete movements every time the heel side of the treadle makes a complete movement. Since the feeder goes up when the needle goes up, and down when the needle goes down, the feeder makes four complete movements for each complete heel movement.

5. The needle travels $2\frac{6}{16}$ in. for a complete stroke and a point on the circumference of the balance wheel travels $9\frac{3}{4}$ in., hence the speed of the needle is one-fourth that of the circumference of the balance wheel.

The balance wheel moves seven times as fast as the heel side of the treadle. The needle, therefore, moves $\frac{7}{4}$ as fast as the heel side of the treadle. The speed or time advantage of the sewing machine is then $\frac{7}{4}$ and its mechanical advantage $\frac{4}{7}$.

60. Foot Force on the Treadle.—The force at the treadle to drive the needle through cloth varies considerably with the position of the crank arm on the drive wheel. A position for the drive wheel was selected that gave the greatest driving force at the needle. The force then to drive the needle through gingham was approximately 4 lb. Increasing the number of pieces increased the force, but not greatly, as it was less than $\frac{1}{2}$ lb. greater when nine thicknesses of cloth were used. Wool required a smaller and cotton a larger force than the gingham.

61. Work Done on and by the Machine.—To obtain some idea of the work done *by* the machine in terms of the work done *on* the machine, different weights were fastened to the top of the needle bar and were raised by weights hung from the toe side of the treadle. The crank arm was always in the same position for each trial and the efficiency obtained is for this position only. The average weight lifted at the needle was 6 lb. and the average weight at the toe side of the treadle to lift the needle was 15.75 lb. As has been shown, the velocity

of the needle is $\frac{7}{4}$ times that of the treadle, so the efficiency of the machine is equal to:

$$\frac{\text{Work done by}}{\text{Work done on}} = \frac{\text{weight on treadle} \times \text{distance moved}}{\text{weight on needle} \times \text{distance moved}} = \frac{6 \times \frac{7}{4}}{15.75 \times 1} = 66.6 \text{ per cent.}$$

62. Horsepower or Rate of Work.—In a given piece of sewing, the heel side of the treadle made 120 complete movements per minute. Let us assume, from the data obtained in getting the foot force on the treadle, that the total force, toe and heel movement, is 8 lb., and that the average distance this force moves through is 2.25 in. Then the work done in foot-pounds is $8 \times 120 \times 2.25 \div 12 = 180$ ft.-lb. This work was done in one minute, so the rate of doing work was $180 \div 33{,}000 = 0.0054$ hp. The usual sewing machine motor is a $\frac{1}{16}$ or $\frac{1}{20}$ hp., which gives ample power for running the machine.

63. One Type of Shuttle.—The illustration shows very clearly the mechanism and action of one type of shuttle.

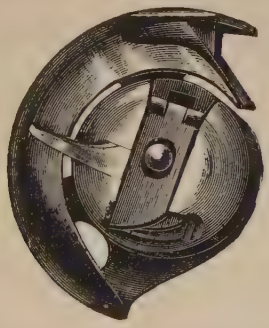


FIG. 36.—Oscillating shuttle and central bobbin in its case.

Study Questions

1. What would be the advantage and the disadvantage of making the lever arms of the treadle equal?
2. Why is the balance wheel made heavy?
3. What effect will a slipping belt have on the amount of work required to run the machine?
4. How is the high speed of the bobbin winder produced?

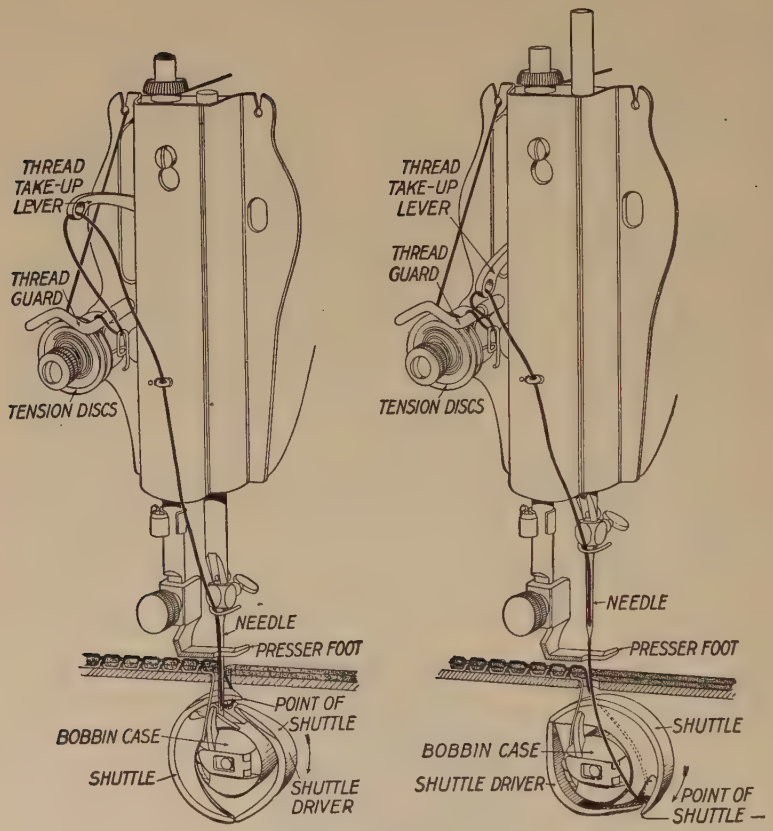


FIG. 37.—Oscillating shuttle.

(*a*)

Point of shuttle entering loop of needle thread.

Figure 37(*a*) shows the first stage in stitch formation. The thread leading to the needle is loosened, because the thread take-up lever has begun its descent; the needle, after having descended to its lowest point, has been slightly raised and a loop of thread is thus formed which is immediately entered by the point of the shuttle. The oscillating shuttle makes part of a revolution during the beginning of each stitch, the direction being indicated by the arrows in Figs. 37(*a*) and (*b*), and during the completion of the stitch the direction of the shuttle is reversed as shown by the arrows in Figs. 37(*c*) and (*d*).

(*b*)

Loop of needle thread enclosing bobbin case.

Figure 37(*b*) shows the second stage. The loop of needle thread has been taken down by the point of the shuttle and is being passed around the bobbin case containing the bobbin of under thread, sufficient enlargement of the loop having been permitted by the descent of the thread take-up lever.

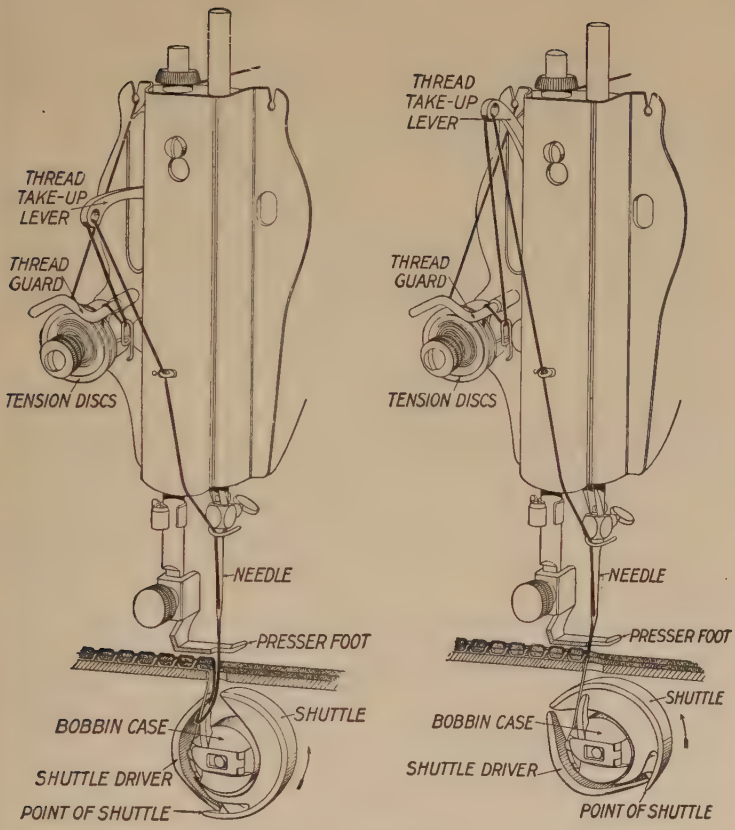


FIG. 37.—(*Continued.*)

(*c*)

Under thread enclosed by needle thread.

Figure 37(*c*) shows the third stage. The loop of needle thread has been cast off from the shuttle, the under thread has been enclosed by the needle thread, and the thread take-up lever is being raised to tighten the stitch.

(*d*)

Stitch completed.

Figure 37(*d*) shows the stitch completed. The thread take-up lever has been raised to its highest point, drawing the needle thread, together with the under thread, into the middle of the fabric, the two threads now being locked. The tension on the needle thread is regulated by the circular tension discs shown in the illustrations, and the tension on the under thread is regulated by a spring on the bobbin case.

Some Suggested Laboratory Exercises

1. The efficiency of a sewing machine.
2. The mechanical advantage of different parts of a sewing machine.
3. The mechanical advantage of various household machines as, tack puller, three types of can openers, scissors, hammer, etc.
4. Experimental study of each of the simple machines.

REVIEW SUMMARY

A machine is a device for transferring work.

The advantage of a machine is in the control of force and distance factors.

Law of ideal machines—work done on the machine equals work done by the machine.

Mechanical advantage is the ratio of resisting force to working force, usually expressed as ratio of two dimensions of the machine.

Mechanical advantage of the lever equals the inverse ratio of its arms.

Mechanical advantage of the wheel and axle equals the inverse ratio of the radii of wheel and axle.

Mechanical advantage of a system of fixed and movable pulleys equals the number of supporting cords or equals twice the number of movable pulleys.

Mechanical advantage of an inclined plane equals ratio of the length of incline to its height.

Mechanical advantage of a screw equals the ratio of distance traveled by the working force in one complete revolution of the screw to the pitch of the screw.

General statements on the mechanics of a sewing machine.

CHAPTER VI

MECHANICS OF LIQUIDS

64. Pressure.—In studying the mechanics of liquids the word pressure should be defined. Pressure is the force applied to any surface divided by the area of the surface, or

$$P = \frac{\text{force}}{\text{area}}.$$

The most used units for pressure are the pound per square inch or per square foot. Steam gages on steam-heating plants, and the water gages found on tanks are nearly always graduated in pounds per square inch.

65. Three Laws of Hydrostatics.

I. The pressure is the same at all points in a horizontal plane of a liquid at rest under gravity.

If the pressure were not the same at any given point in a horizontal plane in a liquid, there would be a force tending to move the particle laterally.

II. The pressure at any point in a liquid at rest under gravity is proportional to the depth.

Have you not observed when in swimming that water does not get into your ears when you dive to moderate depths, but that if you dive to a depth of, say, 10 feet, water always does get into your ears? House builders, in putting a tank in the attic, design the tank so the *walls* will be strong, *not* in proportion to the *volume* of the water it is to hold, but in proportion to the *depth* of the water in the tank.

III. The pressure at any point in a liquid is the same in all directions. This law is a more general statement than that in law I, which considered only one plane.

66. Buoyancy: Archimedes' Principle.—A fresh egg sinks in water but floats in strong brine; a spoon floats in mercury but sinks in brine; wood sinks in alcohol but floats in water.

When you walk out into water up to your neck, you are nearly lifted off your feet. All these facts show that the resultant force of a liquid on an immersed body produces an upward force which tends to balance all or a part of the body's weight. Buoyancy is the term used to denote this resultant upward force. About 240 B.C. Archimedes discovered the law of buoyancy while finding out for Hiero, King of Syracuse, whether his crown was all gold or whether the silversmith had mixed some base metal with the gold.

The law of buoyancy is:

A body immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced.

From law II of the previous article, it is evident that the lower part of an immersed body is subjected to an upward force which is *greater* than the downward force on the upper surface. The buoyant force per unit area is equal to the difference of these forces.

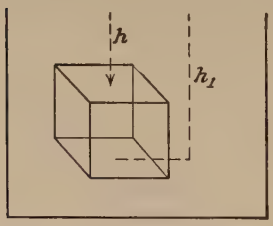


FIG. 38.—Buoyant force.

Assume an immersed cube. The horizontal force on any side will be balanced by the equal horizontal force upon the side opposite. The downward force on the top surface of the cube will be equal to the weight of a column of liquid whose height is h and whose area is the area of the top surface. The upward force on the bottom of the cube, laws II and III, will be equal to a column of the liquid of height h_1 and whose area is the area of the bottom. The difference between these two forces will equal the weight of the liquid that has the same volume as the cube. This gives the buoyant force.

The buoyant force acting on any immersed body is equal to the weight of the liquid whose volume is the same as that of the body.

There are then two forces acting on an immersed body, the earth's pull and the upward buoyant force. When the buoyant force is less than the pull of the earth the body will sink. But if the buoyant force is equal to the pull of the earth, the body will float.

A floating body sinks to such a depth in a liquid that the weight of the liquid displaced equals its own weight.

Cream on milk, fat globules on the soup, Ivory soap on water, a person with a life belt, a row boat are examples of floating bodies.

67. Pascal's Law.—A solid transmits pressure only in the direction in which the force acts. In liquids, the free movement of the molecules over one another causes the pressure to be transmitted in all directions. Pascal stated the law as follows:

Pressure exerted upon any part of an enclosed liquid is transmitted undiminished in all directions.

Let us assume that the waste pipe $1\frac{1}{2}$ in. diameter in the kitchen sink has become stopped somewhere and that it is possible to screw a plug with an opening $\frac{1}{4}$ in. in diameter into the top of the pipe. To this plug is now attached a small bicycle air pump which can create a force of 4 lb. through the small opening. We will apply Pascal's law to find the total force which could be exerted on the stoppage in the pipe.

Area of the waste pipe $= \pi R^2 = 3.14 \times 0.75^2 = 1.76+$ sq. in.

Area of the plug opening $= \pi r^2 = 3.14 \times 0.125^2 = 0.049$ sq. in.

Number of areas in waste pipe equal to area of the plug opening $= 1.76/0.049 = 36$, approximately.

Hence, from Pascal's law the total force exerted will be $36 \times 4 = 144$ lb.

In the study of machines we found that a small force could be greatly increased by the use of a machine. Here we have another means of increasing the force.

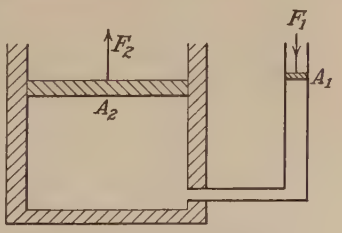


FIG. 39.—Hydrostatic press.

The hydrostatic press (Fig. 39) shows a simple form of the many devices making use of this law.

Let F_1 be the downward force applied to the piston of area A_1, then the pressure transmitted is the same through the system, or

$$p = \frac{F_1}{A_1}.$$

The upward force F_2 exerted on the large piston of area A_2 is

$$F_2 = F_1\left(\frac{A_2}{A_1}\right).$$

Illustrative Problems

1. At a point 10 cm. below the surface of a liquid what is the downward, upward, and lateral pressures? The same. Law I.

2. At a point 20 cm. below the liquid surface what are the pressures in the different directions compared with those in Exercise (1)? Twice as great. Law II.

3. A body of volume 10 cc. is immersed in water. What is the buoyant force on it?

It displaces 10 cc. of water and since one cc. of water weighs 1 g., the buoyant force is 10 g.

4. A cylinder 20 cm. long and 4 cm. in diameter is immersed in a liquid which weighs 13.6 g. per cc. What is the buoyant force on the cylinder?

Volume of the cylinder equals $20 \times 3.14 \times 2^2 = 251.2$ cc.

Weight of the liquid displaced $= 251.2 \times 13.6 = 3{,}416.3$ g. = the buoyant force.

5. In (4) a cubic centimeter of the cylinder weighs 10 g. Will the cylinder float? Yes, since the buoyant force is greater than the weight of the cylinder.

6. A certain cork life preserver weighs 6,000 g. and 1 cc. of cork weighs 0.25 g. How great a buoyant force will it exert on a person when it is completely immersed in water?

The volume of the cork is 24,000 cc. and the weight of the water displaced is 24,000 g., which is the buoyant force. But the cork weighs 6,000 g.; hence, the buoyant force on the person is 18,000 g.

7. A small tin can is 20 cm. high and 6 cm. in diameter. It is filled with water and to the upper end is soldered a tube 25 cm. long and 0.5 cm. in diameter; the tube is filled with water. What is the force tending to burst the can? Neglect the effect of the water in the can.

Pascal's law states that the pressure will be transmitted undiminished to every equal area.

The water in the tube has a volume of 4.9 cc. The weight of the water is then 4.9 g. and the force transmitted to the can is 4.9 g. over an area of $\pi r^2 (= 3.14 \times 0.25^2) = 0.196$ sq. cm. This is equal to a pressure of $4.9/0.196 = 25$ g. per square centimeter. The area of the can is, for the two ends: $\pi r^2 \times 2 = 3.14 \times 3^2 \times 2 = 56.52$ sq. cm.; for the side: $2\pi r \times h = 3.14 \times 2 \times 3 \times 20 = 376.8$ sq. cm. or a total area of 433.3 sq. cm.

To each of these square centimeter areas the transmitted pressure is 25 g., hence the force tending to burst the can is 10,832.5 g.

8. A certain hydraulic press has pistons of areas as 1 to 10. A force of 10 lb. is exerted on the smaller piston. What is the force exerted by the larger piston?

$$F_2 = F_1\left(\frac{A_2}{A_1}\right) \text{ or } F_2 = 10\left(\frac{10}{1}\right) = 100 \text{ lb.}$$

Study Exercises

1. What is the pressure on the bottom of a vessel of area 100 sq. cm. when filled with water to a height of 10 cm.? What would be the pressure on the same area 5 cm. from the bottom?

2. In a vessel 10 × 10 × 10 cm. filled with water, what is the lateral pressure at the bottom? What is it at the top? Then what is the average pressure on one side?

3. Two tanks, each holding 500 lb. of water, have heights of 2 and 6 ft., respectively. Which tank has the greater pressure on its sides? Which tank should be the stronger?

4. A body weighs 100 g. in air and seemingly weighs 80 g. in water. What is the buoyant force of the water?

5. A body of mass 1,000 g. has a volume of 500 cc. Will it float? What is the pull of gravity downward on the body? What is the upward buoyant force?

6. If we assume the difference between the pull of gravity on a person in the water and the buoyant force is 5,000 g., how many cubic centimeters of cork (1 cc. of cork weighs .24 g.) must be immersed in order to support the person?

7. A row boat weighs 400 lb. and when immersed in the water to within 6 in. of the top it displaces 15 cu. ft. of water. What is the maximum load it can carry and have its maximum immersion? One cubic foot of water weighs 62.4 lb.

8. The volume of an average 120-lb. woman may be taken at 2.1 cu. ft. If she is completely immersed under water, what is the buoyant force acting?

9. A 2-in. drain pipe is stopped up. A hose ½ in. internal diameter is put into the drain pipe and the remainder of the opening in the pipe securely closed. The hose is connected to the water system giving a pressure of 20 lb. per square inch. What pressure is being applied to the stoppage in the pipe?

10. A water tank in the attic is 5 ft. long, 2 ft. wide and 4 ft. deep. What is the pressure on the bottom and on the sides when full? A cubic foot of water may be assumed to weigh 62.4 lb.

11. A hot water tank, 10 in. diameter and 60 in. high, is nine-tenths full, and steam is generated at the top, exerting a pressure of 2 lb. per square inch. What is the total force on the tank?

12. If water in the water main at ground level has a pressure of 20 lb. per square inch, what pressure will it have in the bathroom on the second floor 15 ft. above the ground?

13. Why does Ivory soap float while the laundry soap sinks?

14. Is the buoyant effect of water different at different depths? Explain.

15. Explain the action of life preservers.

16. The level of the water in a city reservoir is 100 ft. above the city mains, a kitchen faucet is 10 ft. above the mains, and a bathroom faucet is 20 ft. above the mains. What is the pressure per square inch at each faucet?

17. A bottle of inside area of 50 sq. cm. full of a liquid has its cork of area 0.5 sq. cm. pressed in with a force of 50 g. What is the force tending to break the bottle?

REVIEW SUMMARY

Pressure is the force per unit area.

Pounds per square inch or per square foot are common units.

Pressure in liquids is proportional to the depth.

Pressure in liquids at any point is the same in all directions.

A body is buoyed up by a force equal to the weight of the liquid displaced.

A body floats when the buoyant force is equal to the weight of the body.

Pascal's law states that the pressure exerted on any part of an enclosed liquid is transmitted undiminished in all directions.

CHAPTER VII

DENSITY AND SPECIFIC GRAVITY

68. Density and Specific Gravity.—Density or specific gravity determinations find only a limited application in the household. When made, they usually serve as an index to indicate when a sirup has been boiled down sufficiently or to give an indication of the poorness or richness of the milk and cream.

The density of a substance is defined as the mass per unit volume. The specific gravity of a substance is the ratio of the mass of the substance to the mass of an *equal* volume of the standard substance (which is usually water).

In scientific work the density is usually expressed in the metric system, the mass being in grams and the volume in cubic centimeters. Since 1 cc. of water has a mass of 1 g., its density is 1. In the metric system, the density and the specific gravity of a substance are numerically equal. But in the English system of units, the two are not the same. The density of water is 62.4 lb. per cubic foot, but the specific gravity of water is 1, as can be seen from the definition. The density of milk is 64.27 lb. per cubic foot, but its specific gravity is 1.03.

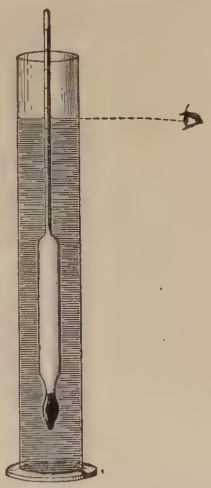


FIG. 40.—Hydrometer floating in a liquid, showing correct position of the eye for reading the scale.

69. The Hydrometer.—The specific gravity of liquids may readily be determined by an instrument called a hydrometer. The instrument floats in the liquid whose specific gravity is to be found, and the specific gravity is determined by noting the point on the stem to which the hydrometer sinks in the liquid. A floating body sinks in any

liquid to such a depth that the weight of the liquid displaced by the body is equal to the weight of the body. When provided with a suitable scale, the floating body may indicate directly the specific gravity of the liquid.

The specific gravity of the liquid is equal to the constant mass of the hydrometer divided by the volume of the liquid displaced. The scale gives these quotients. For liquids denser than water, the scale is calibrated from the top of the hydrometer downward, while for liquids less dense than water the scale is calibrated from the bottom upward.

70. Types of Hydrometers.—Hydrometers sometimes used in the home are of three types: specific gravity hydrometers, percentage hydrometers, and arbitrary scale hydrometers.

The first type has its scale calibrated to read specific gravities directly. The percentage hydrometers are calibrated so as to indicate the percentage of a substance, either by weight or volume, in a mixture or solution of the substance in water. Hydrometers used to determine the richness of milk or cream, called "lactometers," represent the arbitrary scale type.

71. Use of the Hydrometer.—A portion of the liquid that is to be tested is placed in a cylindrical jar of such a size that the hydrometer will not come in contact with the walls. The temperature of the well stirred liquid should be known and should be that for which the hydrometer has been calibrated, if accurate work is to be done. The eye should be held normal with the surface of the liquid at the point where the liquid appears to cut the stem of the hydrometer, and the reading taken at that point.

A hydrometer may be used at temperatures other than the standard temperature. If experience has shown that a certain syrup has the proper consistency when cool, if the hydrometer reads 1.41 when the liquid temperature is 90° F., then the standard temperature need not be used.

	Temperature, Degrees Centigrade	Table of Densities
Dry air	20	0.0012
Air, 50 per cent humidity	20	0.00119
Brine, 5 parts of salt in 100 parts of brine	15	1.035
Butter	....	0.86
Vinegar, cider	....	1.013 to 1.015
Cream, 18 per cent butter fat	20	1.01
Cream, 40 per cent butter fat	20	0.99
Ice	0	0.92
Milk	20	1.028 to 1.032
Olive oil	20	0.91
Maple syrup, 35 per cent water	17.5	1.32
Silk fiber, raw	....	1.3 to 1.37
Silk, boiled off	....	1.25
Wool	....	1.28 to 1.33
Cotton	....	1.50 to 1.55
Linen	....	1.50

Study Exercises

1. The density of pure silver is 10.5. A sterling spoon weighed 100 g. in air and 90.477 g. in water. Was it a pure silver spoon?
2. Milk with a density of 1.030 has 1 qt. of water added to 5 qt. of milk. Will its density fall below 1.026, the lowest value allowable by a certain milk inspection law?
3. It is said that the average person inhales 2,500 gal. of air in 24 hrs. How many pounds of air are inhaled?

Some Suggested Laboratory Exercises

1. Some use of the hydrometers.
2. Density of a soap that floats.
3. Milk and cream densities.

REVIEW SUMMARY

Density defined as the mass per unit volume. Specific gravity defined as the ratio of the mass of the body to the mass of an equal volume of the standard substance, usually water. Specific gravity and density numerically equal in the metric system, unlike in the English system. Hydrometers described and their use indicated.

CHAPTER VIII

GASES

72. Gases.—The gas molecules, like those of a liquid, are free to move under the action of the smallest force and gases are then, as well as liquids, classified as fluids.

Gases transmit pressure equally in all directions, as do liquids, and both liquids and gases have elasticity of volume, for on removing the pressure to which either has been subjected, it returns to its original volume. The compression of gases is much greater than that of liquids. Both liquids and gases have weight, but the mass per unit volume of the two differ greatly. One liter of water weighs 1,000 g. under standard conditions, while a liter of air weighs but 1.293 g.

73. Atmospheric Pressure.—The air surrounding the earth may be thought of as a great gas ocean, with the earth as its floor. The pressure on any area of this floor is due, as in the case of the pressure on the sea floor, to the weight of the fluid above it. This pressure which at sea level is 14.7 lb. on each square inch of surface, decreases as we move upward from the earth. At the summit of Mr. Rainier, which is the highest mountain in the United States, excluding Alaska, the pressure is approximately 8.33 lb. per square inch. If the surface area of the average woman is taken as 16.5 sq. ft., the body is sustaining a force of 35,640 lb. If the body were a hermetically sealed box, this outside force would crush it, but the air in the body is pressing outwards with the same force and we are able to move as freely as if there were no pressure on our bodies.

Since we, as well as all other bodies, are immersed in air, there is an upward pressure equal to the weight of the air displaced. The apparent weight of a body as ordinarily found is *less* than its true weight by the weight of its own

volume of air. If we assume the volume of a 120-lb. woman to be 2.1 cu. ft., then her true weight is 120 + 0.17, or 120.17 lb.

74. The Barometer.—We owe to Torricelli, a pupil of Galileo, the instrument for determining the pressure of the atmosphere. A tube closed at one end is filled with mercury and the open end is placed in a vessel of mercury. The pressure of the air on the surface of the vessel, exerted equally in all directions, just balances the weight of the column of mercury in the tube. If this air pressure varies, then the height of the mercury in the tube changes. At sea level the mercury stands 76 cm. or 30 in. above the level in the vessel, and the weight of a column of mercury 1 sq. cm. or 1 sq. in. in area (of these heights) is 1.0333 kg., or 14.7 lb.

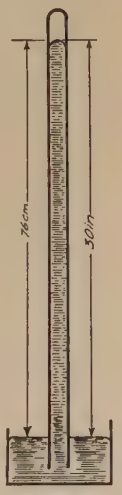


FIG. 41.—The barometer.

75. The Barometer and the Weather.—Wind, or air in motion, results from a difference in the atmospheric pressure in two different places. Storms or rain clouds travel with the wind, hence they move toward places of low pressure. A sudden drop in the barometer, then, usually indicates the approach of a storm; while a rapid rise shows a movement of air, with its rain, away from the place. A knowledge of the simultaneous barometric readings of stations scattered over a large area, enables the weather bureau to predict the probable weather over a given region in advance.

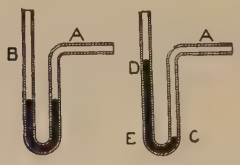
76. Boyle's Law.—Robert Boyle investigated the relation between the volume of a gas and the *pressure* and found that *at a constant temperature the volume of a given mass of gas varies inversely as its pressure.*

If 1 cu. ft. of the gas used for domestic cooking at a pressure of 14.8 lb. per square inch had its pressure *increased* to 16 lb. per square inch, the *decreased* volume would be 0.925 cu. ft. Stated as an *inverse* proportion, we have

$$1 : X :: 16 : 14.8 \text{ or } X = 0.925 \text{ cu. ft.}$$

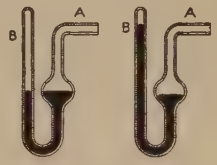
77. Open and Closed Manometers.—A manometer is a device for measuring fluid pressures. The barometer is a manometer which measures atmospheric pressure. Two other types of manometers are common, the open type (Fig. 42) for measuring pressures not much greater than that of the atmosphere and the closed type (Fig. 43) for measuring pressures much greater than that of the atmosphere.

The open manometer, as the figures show, consists of a bent tube partly filled with some liquid, as water or mercury, the end A being connected with the gas, the pressure of which is to be measured.



(*a*) (*b*)

FIG. 42.—Open-type manometer.



(*a*) (*b*)

FIG. 43.—Closed type of manometer

Figure 42(*a*) shows the manometer with equal pressures on each limb, while Fig. 42(*b*) shows the result when the pressure at A is greater than the atmospheric pressure. The weight of the column of liquid DE measures the excess pressure over that of the atmosphere. If water is the liquid in the manometer and A is connected to a gas outlet in a home, the column DE would be from 2 to 4 in. high and the *excess* pressure of the gas over that of the atmosphere would be stated as being equal to 2 to 4 in. of water. The total pressure is, say 14.7 lb. plus the weight in pounds of a column of water 2 to 4 in. high and 1 sq. in. in area.

The closed type of manometer is similar to the open type except that the B end is closed and the space below B is filled with air. The liquid used is generally mercury. Figure 43(*a*) represents the manometer with equal pressure in the two limbs, that of the atmosphere. If the end A is now connected to the city water main outlet in a home, the mercury will rise in B and fall in A (Fig. 43(*b*)) and the volume of air in B will be

less. Boyle's law will enable the pressure of the water in the main to be found. Let us assume that the volume of enclosed air originally 100, is now 42.3+. Then

Original volume of air : new volume :: new total pressure : original pressure or

$$100 : 42.3 :: X : 14.7$$
$$X = 34.7 \text{ lb. per sq. inch.}$$

As the pressure in B was 14.7 lb. originally, and is now 34.7 lb., the water pressure in the mains is 20 lb. per square inch.

78. The Gas Meter.—The gas, as supplied to houses, comes from the mains at a pressure slightly greater than that of the

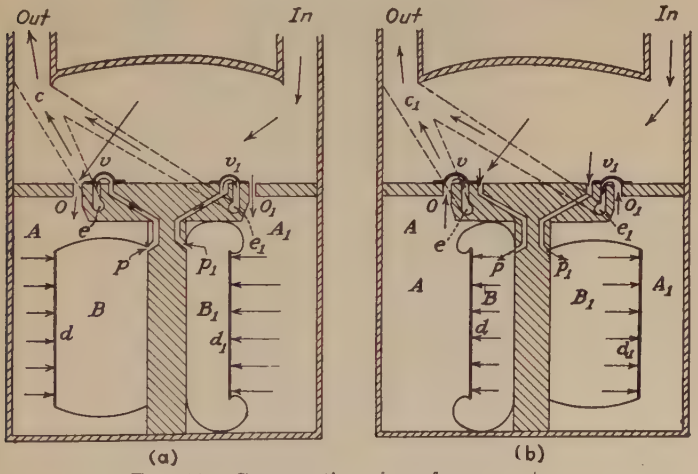


FIG. 44.—Cross-section view of a gas meter.

atmosphere, the excess pressure being equal to that of 2 to 4 in. of water. The mechanism of the gas meter is shown in Fig. 45 and cross-section views in Fig. 44.

The gas from the mains enters the meter at *In* (Fig. 44(*a*)) into the chambers A and A_1 through O and O_1. The moving bellows d and d_1 are both forced inward by the pressure of the gas so that the gas already in B and B_1 is forced out through p and p_1 into the outlets e and e_1 which unite to form the outlet C to the distributing main of the house. As these two bellows

move inward, a lever operated by their movement works the slide valves v and v_1 causing them to move in the opposite

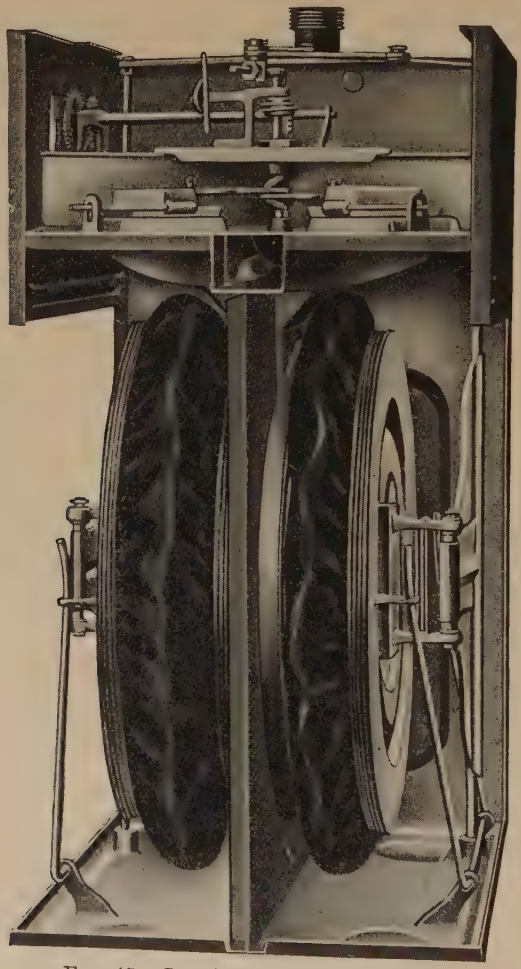


FIG. 45.—Interior view of a gas meter.

direction. When d_1 has moved as far inward as it can, the valve v_1 no longer connects p_1 and e_1 but connects O_1 and e_1, thus leaving p_1 open to the gas from the main inlet. The gas

now entering B_1 forces the bellows d_1 outward, (Fig. 44(b)) and the gas in A_1 is forced out through O_1 and e_1 to outlet C_1. When d_1 is halfway out and the bellows d is as far as it can go, the valve v then connects O and e and gas enters B through p_1 while the gas in A is forced out through O and e. Since B and B_1 are not empty at the same time, a steady flow is maintained through outlet C. A clockwork device, connected to a system of levers worked by the moving bellows, operates the dials which record the amount of gas passing through the meter.

(a) (b)

Fig. 46.—Gas-meter dials.

The dials are read from *right to left.* If the hand is very nearly over one of the figures on a dial the dial of next *lower* value must be consulted to see whether the figures under the hand or the one just previously passed by the hand should be read. Figure 46(a) shows from the middle dial reading that the left-hand dial should be read 7 not 8. The correct reading is 79,500. In Fig. 46(b) the correct reading is 68,900.

Study Exercises

1. Which type of manometer would you use to find the pressure in the water system? In the gas mains? Explain.
2. When a vacuum incandescent lamp explodes is there much danger of the glass flying outward? Why?
3. If a can of baked beans, 4.75 in. high and 3.75 in. diameter is placed in boiling water until the air and steam exerts a pressure of 2 lb. per square inch, what is the total force on the can?
4. Why should 1 lb. of pop corn weigh less than 1 lb. when popped? Neglect any loss due to evaporation of the water.
5. Could you carry the air in the lecture room, which is 60 ft. long, 40 ft. wide and 15 ft. high? What is the weight of this air?
6. As gas meters become worn with usage are they more likely to register too much or too little?

7. A closed vessel has 100 cc. of air under a pressure of 15 lb. per square inch. What is the volume of the air when the pressure is raised to 45 lb.?

8. A closed manometer has an enclosed column of air 10 cm. high under a pressure of 14 lb. per square inch. When the manometer is connected to the water system the column of air is reduced to 4 cm. What is the pressure in the water system?

9. Our gas meters register volume. If the gas is delivered to our home at a pressure of 14.7 lb. plus that of 2.5 in. of water, and at another time at a pressure of 14.7 lb. plus 5 in. of water, in which case do we get the more gas in 1 cu. ft.?

PUMPS

Pumps for domestic purposes are made in one of two types, the lift pump and the force pump.

79. The Lift Pump.—The kitchen pump is of the lift type and is representative of the pumps used for nearly all household purposes where the water is to be raised from cisterns. It is generally made of cast iron. The maximum "lift" of such a pump is seldom over 20 ft. and in actual practice is nearer 10 ft. The figure shows a cross-section of the working parts of such a pump.

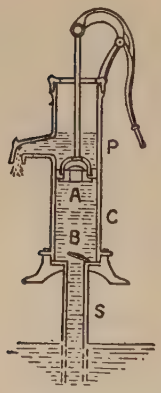


FIG. 47.—Cross-section of a kitchen pump.

The upper part of the pump consists of a cylinder in which a closely fitting piston P with a valve A moves up and down. At the end of the cylinder is another valve B. The pipe S extends into the cistern.

The pump operates as follows: With the piston at the bottom of the cylinder, the handle is moved down, which raises the piston. The air in the cylinder has been rarefied and exerts a smaller pressure on the valve B than the air in the pipe. The water in the pipe is accordingly pushed up due to the greater pressure of the atmosphere outside. After repeated strokes of the piston the water is pushed up to the valve B, which raises and lets some of the water into the cylinder. On the downward movement of the piston, the valve B is closed. When the cylinder is filled with water the downward movement of P

raises the valve A, and on the upward movement of the piston the water is lifted out through the spout.

The valve A is a hinged or loose piece of iron, so planed on its lower surface as to make good contact with the opening in the piston. The valve B is of leather with a metal back. The leather makes a tight joint at the cylinder end. The piston is surrounded with a ring of leather which causes it to fit tightly in the cylinder. When this leather ring or gasket gets worn or dry, the piston fits loosely in the cylinder and the pump cannot lift the water easily because of the leakage around the piston. A leakage around the valve B will allow the water to go back gradually into S. Then when the pump is idle it will lose its "priming." Priming a pump consists in filling the cylinder with water before pumping. As soon as the leather around the piston and in the valve B becomes water soaked the pump will work again.

80. The Force Pump.—The force pump can be used in a small way for lawn sprinkling and for fire protection. It finds a better use in raising water into small and not very high

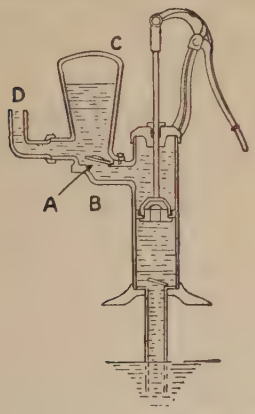


FIG. 48.—Section of a force pump.

FIG. 49.—Deep well pump.

water-supply tanks or for small pressure tanks. The essential differences between it and the lift pump are the absence of a valve in the piston, the addition of a check valve and an air chamber for putting the water under a pressure. The figure shows the working parts.

The action of the pump in raising the water is the same as in the lift pump. The valve *A* prevents the water returning to the cylinder after it has been forced out. If the outlet *D* is smaller than the opening *B*, some of the water will enter the chamber *C* and compress the air and this compressed air will, when the piston is descending, force the water out of the chamber and into the pipe *D* since the check valve prevents its return to the cylinder. Thus the pump delivers a fairly steady stream of water instead of the intermittent flow of the lift pump.

For wells, the force pump is usually modified by having the piston and valve placed in a cylinder which is nearer the water, or in the case of deep wells, in the water. The atmospheric pressure can lift water not much over 20 ft. in practice, and so by placing the piston near the water such a pump can be used to raise water from deep wells. Its action is not different from the force pump already described. The figure shows a deep-well pump.

VACUUM SWEEPERS

81. Introduction.—In all the first attempts to replace manual labor by machinery the result was a machine that imitated the tools formerly used by the man or woman. The earliest steamboats were mechanical rowing machines, the earliest flying machines were mechanical birds, and the earliest mechanical sweepers were in the form of mechanical brooms.

The familiar carpet sweeper came into existence about 1880 and was a revolving broom or brush enclosed in a case, the brush being driven by friction from the wheels. The power was supplied by the person who pushed the sweeper over the carpet. This machine, which has won its way into thousands of homes, has had no marked improvements made on it for years.

82. Limitations of the Carpet Sweeper.—The carpet sweeper has always been a surface sweeper, removing the dirt and litter that, being on the surface, is so annoying to the housekeeper because it is directly before her eyes. By its construction it is impossible to operate it under low furniture, and, like the lawn

mower, it must be in motion in order to do its work. The corners, along the walls, or close to heavy furniture are impossible places to use it. On bare floors it has never been a success and has never displaced the dustpan and broom. It is chiefly a "slicking up" device and holds its place today because of this fact.

83. Portable Vacuum Cleaners.—The first portable vacuum cleaner was made about 1905 by Dr. Willam Noe of San Francisco. In the years that have passed, the number of different types of vacuum cleaners has increased very greatly. There are at least 30 different makes of the small portable type used in the home.

84. Vacuum Cleaners and Sweepers.—There is a difference, at least in degree, between a sweeper and a cleaner. A vacuum cleaner is a machine which by virtue of its high vacuum, measured in inches of mercury or in inches of water, and a fair amount of air exhausted, can remove the dirt from within the carpet as well as do surface cleaning. A sweeper is a machine ordinarily with a much lower vacuum and a larger air displacement. It removes the surface dirt, but is not so satisfactory for withdrawing the dirt deeply embedded in the carpet.

The small and popular vacuum cleaners, weighing from 10 to 20 lb. are not cleaners so much as sweepers. If efficient, they remove surface dirt and some of the interior dirt, but a dirty carpet is swept, not cleaned, by them. Their daily or frequent use in the home tends to lessen this disadvantage, as the dirt does not have so great an opportunity to work itself down into the carpet.

For *cleaning* ability a vacuum machine should have a vacuum of not less than 1 in. of mercury when being operated. Its ability to clean will increase, other factors being kept constant, with the increase in the vacuum produced.

For *sweeping* ability a vacuum machine needs large air displacement and its sweeping ability is increased as the air displacement is increased.

The Light-weight Sweeper.—The light-weight portable vacuum sweeper, of which there are many makes, is almost

without exception a fan machine. A small fan is placed in the base of the machine and is rapidly revolved by a small electric motor. This fan throws the air in the base into the bag, through which it escapes into the room. The partial vacuum thus created in the base makes it possible for the air from the outside to rush in, carrying the dirt with it.

Fig. 50(*a*).—Vacuum sweeper.

In the nozzle there is nearly always found a brush. It serves to pick up the small litter and to some extent to loosen the dirt so it can the more easily be taken up by the machine. The brush is either stationary or revolves. If the brush is connected to the motor it may produce a decided wearing action on the carpet.

The electric motors are of the universal type, so they can be used on direct- or alternating-current circuits, and are usually about 0.2 hp. At 10 cts. a kilowatt-hour, the cost of running the sweeper 1 hr. is 1.5 cts. A control switch should be placed

for convenience on the handle end so the sweeper can be started or stopped by a half turn.

The dust bag is an important part of the sweeper. It must allow the air to escape and yet must retain the fine dirt. Some of the finest dirt, however, will pass through the bag into the room. The bags as made at present are hard to clean, although this can be lessened by letting the machine blow out

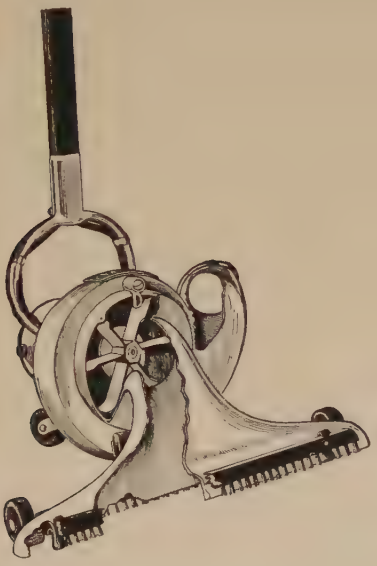


FIG. 50(*b*).—Sectional view of a vacuum sweeper.

the fine dirt which clings so tightly to the bag, the operation being performed out of doors. A special type of paper bag is now on the market which can be used for a time, then thrown away.

The attachments, which usually consist of a hose and several tools, add to the usefulness of the machine. With them bare floors, books on shelves, curtains, mattresses, steam or hot-water radiators, wall mouldings, etc., can readily be cleaned.

85. Data on Vacuum Sweepers.—There seems to be little or no published data on these small machines. The writer

has made some tests and will use his meager data to show what some machines will do.

Three machines were tested for the volume of air displaced per minute while sweeping on a carpet of average grade. Sweeper No. 1 displaced 40 cu. ft. of air per minute, while sweeper No. 2, made by the same company but a later model, displaced 100 cu. ft. per minute. Sweeper No. 3 displaced 60 cu. ft. per minute.

Sweeper No. 1 produced a vacuum of 4.8 in. of water; sweeper No. 2, 4 in.; sweeper No. 3, 4.2 in. These data were obtained while the machines were in operation on the carpet. The sweepers were tested for amount of dirt actually removed from two different grades of carpets, one a fair grade of Brussels carpet and one a high grade Wilton.

The test dirt consisted of a mixture of sweepings, fine sand and flour. The dirt was spread fairly evenly over the carpet and then ground in by walking on the carpet and rubbing the shoes over it.

Brussels Carpet:
Sweeper No. 1 removed 72 per cent of the dirt added.
Sweeper No. 2 removed 95 per cent of the dirt added.
Sweeper No. 3 removed 86 per cent of the dirt added.
Wilton Carpet:
Sweeper No. 1 removed 60 per cent of the dirt added.
Sweeper No. 3 removed 90 per cent of the dirt added.

A vacuum *cleaner* of the semi-portable type, giving a vacuum of 2.5 in. of mercury, was used on the Wilton carpet after sweeper No. 3, and 12 g. of dirt were removed. As only 100 g. were put on the carpet at the beginning, the cleaner took out 2 g. of the dirt embedded in the carpet. A third sweeping was made with a more powerful cleaner and 1.8 g. more of dirt was removed. A vigorous shaking of the strip of carpet gave evidence that there was some dirt still in the strip.

Study Questions

1. Why must a special attachment be put on the cleaner for use on bare floors? Should it fit more closely to the floor or to the carpet?
2. Is it wrong to say that a vacuum sweeper sucks up the dirt from the carpet?

Some Suggested Laboratory Exercises

1. Use of a manometer to measure gas and water pressures.
2. A study of the gas meter.
3. Test of the sweeping ability of three different types of sweepers.

REVIEW SUMMARY

Transmission of pressure in gases same as that in liquids.

Compression of a gas very much greater than that in liquids.

Atmospheric pressure at sea level 14.7 lb. per square inch.

Barometer, a device for showing changes in the pressure of the atmosphere. Under standard conditions, the mercury in a barometer stands at 76 cm. or 30 in. above the level of the containing vessel. Normal weight of the air is 1,033 g. per square centimeter, or 14.7 lb. per square inch.

Barometer level changes used to indicate weather changes.

Boyle's law. Volume of a gas at constant temperature varies inversely as the pressure.

Open manometer for measuring small pressures.

Closed manometer for measuring larger pressures.

Description of operation of a gas meter.

Common lift pump, force pump, and deep-well pump.

Limitation of old type of carpet sweeper.

A sweeper, a device operating at a low vacuum and a fairly high volume of air.

A cleaner, a device operating at a higher vacuum and a moderate volume of air.

Portable home vacuum sweeper, fan type.

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CHAPTER IX

SOUND

86. Sound Waves.—Sound comes to us in waves, usually in the atmosphere, which affect the auditory nerves. Experiment shows that these waves are always produced by a vibrating body. When a large tuning fork is struck, we can see the vibrations of the prongs and can hear the sound. Tracing the sound from the moving prongs to the ear, we may picture the first layer of air near the fork as being set into vibration, and this layer in turn setting the next layer into motion, and so on, until the layer next to the drum of the ear strikes the drum. The passing on of the energy of the vibrating fork from air particle to air particle by putting each in turn in vibration, constitutes a sound wave.

There are many waves of this kind which do not produce sound for the human ear. Some bodies vibrate so rapidly that the waves reaching the ear are not able to produce the sensation of sound. Again some vibrations are so slow that the ear drum does not register any effect. For the average normal person, vibrations above 36,000 per second and below 16 per second are not audible. The table gives some idea of the range of vibrations ordinarily used in sound.

32 vibrations per second produce about the lowest musical sound.
128 vibrations per second produce man's voice in conversation.
512 vibrations per second produce woman's voice in conversation.
2,000 vibrations per second produce a high soprano.
4,000 vibrations per second produce a high musical note.

It is evident from the above table that the range of usable vibrations is very limited.

87. What Carries Sound?—An elastic medium is necessary for the transmission of sound. This medium is ordinarily the air but other gases and liquids, and solids, may act as

transmitters. When one is swimming under water, if two stones are struck together the sound is very loud. The walls and floors of the home are examples of solid transmitters.

88. Speed of Sound.—In carrying on a conversation in an ordinary room one is not aware that it takes time for the sound to travel from the speaker to the ear of the hearer, but in large halls one may hear an echo which is the sound coming to our ears after one or more reflections from a wall. This sound has traveled a longer distance than the direct waves from speaker to hearer and has required a longer time to reach us. The time interval between the flash of lightning and the clap of thunder is due to the slower speed of the sound as compared with the speed of the light. Use is made of this in determining the distance away of the storm by allowing a mile for each 5-sec. interval between flash and clap.

Extensive experiments give 1,087 ft. per second as the speed of a sound wave in air at 32° F. The speed increases about 1.08 ft. for each degree of rise in temperature. The speed in water is about 4.5 times the speed in air, and in steel it is more than 15 times greater than in air.

It may be shown that the two factors upon which the speed of a sound wave depend are the elasticity of the medium and the density of the medium. For liquids and solids, these factors are related as follows:

$$V = \sqrt{\frac{E}{d}}.$$

Example: For copper the elasticity factor as found by experiment is 120×10^{10} and the density of copper is 8.8

Therefore,

$$V = \sqrt{\frac{120 \times 10^{10}}{8.8}} = 369{,}000 \text{ cm. per second} = 12{,}108 \text{ ft. per second.}$$

The value by direct experiment is in close agreement. For gases the factors are related by the equation:

$$V = \sqrt{\frac{1.41E}{d}} = \sqrt{\frac{1.41P}{d}},$$

where P is the pressure of the gas, and, for air, is the barometric pressure.

Example: For dry air when the barometer stands at 76 cm., the pressure P in absolute units is $76 \times 980 \times 13.6$ and the density of the air at 0°C. is 0.001293.

Therefore,

$$V = \sqrt{\frac{1.41 \times 76 \times 980 \times 13.6}{0.001293}} = 33{,}230 \text{ cm. per second} = 1{,}089 \text{ ft. per second.}$$

89. A Wave-length.—While a particle which is vibrating makes a complete vibration as a pendulum swinging from extreme left to right and back to left, the wave travels out in the medium a certain distance and this distance is known as the wave length for that particular wave motion. If a tuning fork makes 100 vibrations per second, the wave travels for each vibration a distance of a wave length, and the total distance the wave or sound has traveled while the fork made the 100 vibrations will be 100 times the wave length or distance the sound traveled during one vibration. Hence,

$$V = nwl$$

where n equals the number of vibrations per second and wl the wave length.

Illustrative Problems

1. If in speaking the sound makes 640 vibrations per second and the velocity of the sound is 1,087 ft. per second, then the wave length is:

$$1{,}087 \div 640 = 1.7 \text{ ft.}$$

2. A certain string on a piano sends out a sound wave whose length is 1.06 ft. when the velocity of the sound is 1,087 ft. per second. The vibration rate of the sound is $1{,}087 \div 1.06 = 1{,}024$ vibrations per second.

3. If a high soprano produces a note of 2,000 vibrations per second, the wave length being found to be 0.575 ft. in a warm room, the velocity of sound at the time is: $2{,}000 \times 0.575 = 1{,}150$ ft. per second.

90. Musical Sounds and Noises.—Sounds are divided into two general classes, noises and musical sounds or tones.

Noises result from irregular vibrations of the air as for example, from knocking over a pile of tin pans. Musical sounds are produced by regular vibrations.

The figures bring out the irregularity and the regularity resulting from noises and musical notes.

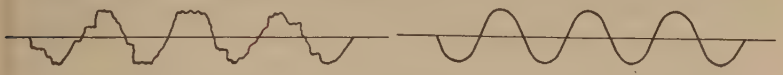


FIG. 51.

(*a*) Noise, irregular vibrations. (*b*) Musical note, regular vibrations.

91. Characteristics of Sounds.—Sounds may differ in three other important ways:

1. *Pitch.*—Male voices are of a lower pitch than female voices. The middle C on the piano is of a lower pitch than the C note an octave above. Pitch depends upon the number

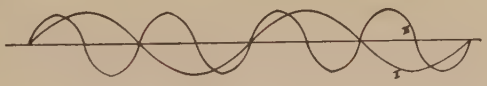


FIG. 52.—Two waves of pitch 1:2.

of vibrations made per second by the sounding body. The middle C note makes 256 vibrations per second, while the C note an octave above makes 512 vibrations per second.

2. *Intensity and Loudness.*—The intensity of a sound depends upon the amplitude of the vibrating particle. If a

FIG. 53.—Two waves of intensity 1:4 same pitch.

piano string is struck so that the movement up and down of the string at its center is $\frac{2}{10}$ cm. in one case and $\frac{4}{10}$ cm. in another case, the intensity is greater in the second case. But it is four times greater, not twice as great. The intensity varies

as the square of the amplitude of the vibrating body. This follows simply, if one considers the energy of the two vibrating bodies. The number of vibrations per second made by the string in the two cases is the same. Hence, the velocity of the vibrating string is twice as great in the second case as in the first case. The kinetic energy of a body, we found in mechanics, is measured by

$$\tfrac{1}{2}mv^2$$

so when the velocity is doubled the energy is four times greater.

Loudness is the intensity of the sound as perceived by an individual ear. Two persons may differ as to the loudness of a sound, but not as to its intensity.

92. Intensity and Distance.—The intensity of a sound varies inversely as the square of the distance from the source. To two persons at 100 ft. and 200 ft., respectively, from a sounding body the intensities would vary as $2^2:1^2$ or as 4:1.

When a sound is produced the waves spread out in all directions and at any given instant the air particles on the surface of a sphere, with its center the source of the sound and its radius the distance the sound has traveled up to the given instant, may be considered as having all the energy of the original source. If two hearers are 5 ft. and 10 ft., respectively, from a given source, they are receiving sound from a part of the surfaces of two spheres whose radii are 5 ft. and 10 ft., respectively, and whose surfaces are in the ratio of 25:100. Since both spheres may be considered as having the same total energy, the energy of the individual air particles on each sphere will be in the ratio of 4:1 and the intensities will be in the same ratio.

93. Intensity, Area and Density.—In general the intensity of a sound increases with the area of the sounding body and with the density of the medium through which the sound travels. The sounding board of the piano and the box of the violin, which are thrown into vibrations by the strings, produce the volume of sound. Sounds traveling through air and water from the same source are more intense in the water.

94. Graphical Representation of a Sound Wave.—Before discussing the last characteristic of a sound wave, let us consider how we may graphically represent a wave. We shall then understand better the curves already used and the new ones to be used in the next article.

Let the dots MM in the (Fig. 54(a)) represent a series of undisturbed air particles.

If now a sound wave is passing along these particles and at any instant we imagine a snapshot is taken of the series, the grouping of the particles will be something like that shown in Fig. 54(b).

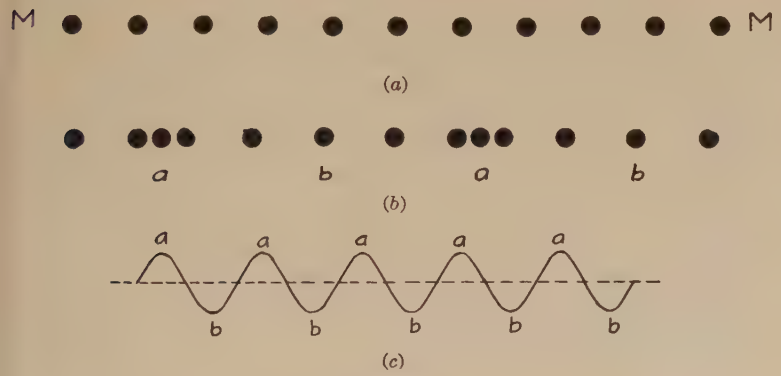


FIG. 54.

The particles are seen crowded together in certain portions, called "condensations," and drawn apart in other portions, called "rarefactions." We may represent the disturbance in the series by a sine curve where the portions of the curve above the normal line of the undisturbed particles indicate compressions, the degree of compression being shown by the distance of the curve from the normal line, and the rarefactions by the curve below the line (Fig. (54(c)). The student should keep in mind that the *actual* motion of the particles is always *along* the line, not at right angles to it.

The curves already used represent simple waves. But if two tuning forks are sounded side by side, the air particles are made to carry both waves simultaneously and the resultant

wave is not simple but complex. The figure shows the simple waves and the complex wave from the two forks.

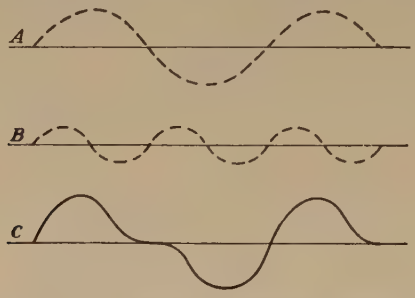


FIG. 55.—Simple and complex waves.

95. Quality or Timbre.—The third characteristic of a sound wave is quality. The quality of a musical tone is that which makes it possible to distinguish between sounds coming from different sources even when their pitch and intensity are the same. A violin and a piano both sound the middle C note. There is little difficulty in distinguishing between the two sounds. The notes produced by a Melba may, in pitch and intensity, be the same as the note you can sing, but everyone will agree there is a real difference. The quality is vastly different.

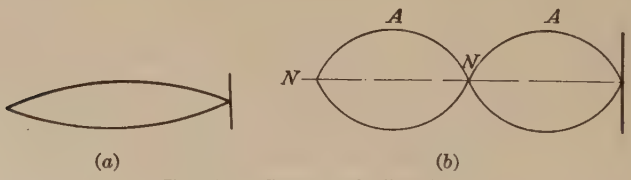


FIG. 56.—Segmental vibration.

Sounding bodies may vibrate, and in general do vibrate, so as to produce a complex wave, not a simple one. A violin string may vibrate not only as a whole, giving out its lowest tone, called its fundamental, but also at the same time vibrate in halves, thirds, etc. The sounds produced by the segmental vibrations of the string are called overtones.

The resulting sound wave in such cases is complex. The figure shows the complexity when a fundamental vibration

and one overtone of frequency two times the fundamental is present (see Fig. 55*C*).

The quality of a musical sound is determined by the *overtones present and their relative intensities.* The curves show why the quality of various musical instruments differs.

Figures 57(*a*), (*b*), (*c*), and (*d*) represent the character of the sounds from the different sources. The smooth curve *a* shows the absence of overtones in the sound of the tuning fork and hence the absence of any definite quality or timbre. Curves

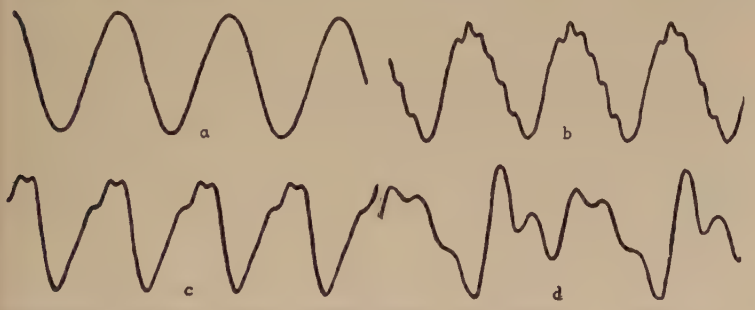


FIG. 57(*a*).—Tuning fork—quality poor. (*b*) Violin. (*c*) Flute. (*d*) Human voice.

b, *c*, and *d*, show the presence of different overtones of varying intensity in each, and hence indicate the distinctive quality or timbre of the sounds produced.

96. Musical Scale.—In comparing two musical tones, we first consider their pitch with respect to each other. The ratio between their pitch or frequencies is known as the musical interval. The interval is the *octave* when the ratio of the two frequencies is 2:1. The principal intervals used in music are given in the table.

Name of Interval	Ratio of Frequencies
Unison	1:1
Octave	2:1
Fifth	3:2
Fourth	4:3
Third	5:4
Minor third	6:5
Minor sixth	8:5

Experience shows that a pleasing effect is produced by two notes sounded simultaneously when the ratio of their frequencies can be expressed by small numbers. In the table of intervals the pleasing effect decreases as one goes from unison to the minor sixth. Consonance is the name given to this pleasing effect. Dissonance results when the ratio of frequencies must be expressed by large numbers.

The ears of Occidental peoples have recognized for centuries that an especially pleasing effect is produced when four notes are sounded whose frequencies are as 4:5:6:8. This combination is known as the major chord and the first three as the major triad. Our major diatonic scale is built up of a combination of major triads and a major chord.

The first, third and fifth notes in the scale form a major triad, as also the fourth, sixth, and eighth, and likewise the fifth, seventh, and ninth (or octave of the second). This is shown in the table.

do	re	mi	fa	sol	la	si	do	re
4		5		6			8	
			4		5		6	
				4		5		6
256	288	320	341⅓	380	426⅔	480	512	576

If *do* in the above table is taken as a note of 256 vibrations per second, then the second table gives the vibrations of the notes in a major diatonic scale, called the "Key of C," since the 256 note is the middle C on the physicist's scale.

If we divided the second note 288 by 256, the quotient is 9/8 and this is the *interval* between the first two notes. The third note divided by the second will give 10/9. Proceeding in this way, we find that this diatonic scale is made up of eight notes with the intervals given below:

C 9/8 D 10/9 E 16/15 F 9/8 G 10/9 A 9/8 B 16/15 C′.

We may build up in this way as many major diatonic scales as there are different notes, provided always that intervals of the same value and the same order as above are used. For example:

Key of D:

288(9/8) 324(10/9) 360(16/15) 384(9/8) 432(10/9) 480(9/8) 540(16/15) 576.

97. Transposition.—It is desirable to make use of scales having other key or tonic notes than C. But each new key adds some new notes and the total number of new notes in the octave in order to play in any key becomes large. It is only practical to have all these new notes in the octave on instruments, such as the voice or the violin. On keyboard instruments, the addition of so many notes would be mechanically impossible. Some compromise must be made.

So far we have neglected the fact of there being two scales, the major and the minor. Just as the major scale is built up from major triads, so the minor scale is similarly made from minor triads. The minor triad consists of notes whose relative frequencies are as 10: 12: 15. In the major scale, Key of C, E: G: B is a minor triad. To transpose then from one key to another or from one scale to another would require the addition of still more notes to the octave.

To overcome this real difficulty, the various different intervals of the natural scale have been so changed that fewer notes will be required to make the transposition. The new musical scale is a compromise; some of its notes have been sharped and some flattened from those required by the natural scale. This new scale is known as the equal-tempered scale. The successive intervals have been made equal. Instead of intervals of 9/8, 10/9, etc., the interval between the notes is 1.05946. The table will make clear the changes this produces.

Education accounts for our acceptance of the equal-tempered scale. As Donkin says:

> The whole structure of modern music is founded on the possibility of educating the ear not merely to tolerate and ignore, but even in some degree to take pleasure in slight deviations from the perfection of the diatonic scale.

To play the major scale Key of C, counting black and white keys, you strike the keys 1, 3, 5, 6, 8, 10, 12, 13. To play in

another key as E, for example, you strike keys 1, 3, 5, 6, 7, 10, 12, 13, counting from E as 1.

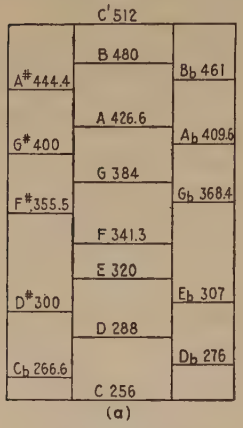


FIG. 58(*a*).—Physicist's natural scale.

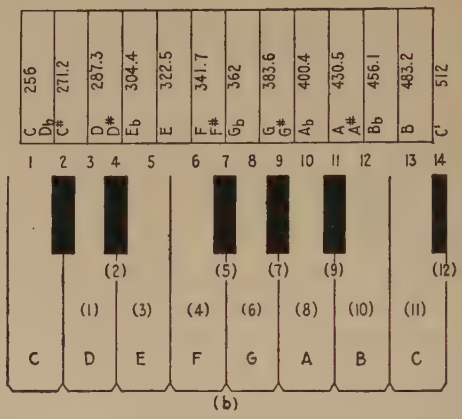


FIG. 58(*b*).—Equal tempered scale. Based on C = 256.

98. The Piano.—Everyone is familiar with at least the outside appearance of the piano. The key board has usually 88 keys or a range of over six octaves. If we look inside we find many wires of different lengths and diameters, fixed to a rigid metal frame and a thin wooden sounding board. If the sounding board were absent, little sound would be given out. The increase in the intensity of the sound is due to the large area that vibrates.

The blow given to the keys is transmitted by an ingenious system of levers to a felt-covered hammer which delivers the blow to the strings.

An examination of the hammer actions will show that the long and large wires are struck to produce the low pitch notes and that the short wires produce the high notes. There is evidently some relation between the size and length of the wires and the pitch or frequency of the notes produced.

Experiments show these relations to be as follows:

1. For a given string the vibration frequency varies inversely as the length of the string.

$$N : N_1 :: L_1 : L.$$

For example, to produce a note an octave higher than that given by a certain string, its length must be reduced one-half.

$$1:2::L_1:L.$$

2. For a given string the vibration frequency varies as the square root of the tension:

$$N:N_1::\sqrt{T}:\sqrt{T_1}.$$

For example, if a string gives a note of 320 vibrations when it is stretched by a force of 16 lb., its pitch will be 400 when the tension is 25 lb.

$$320:400::\sqrt{16}:\sqrt{25}.$$

The piano tuner, since the piano strings are of fixed lengths, changes the vibration rates of the different strings by varying the tension.

3. For a given string, the vibration frequency varies inversely as the diameter of the string.

$$N:N_1::d_1:d.$$

For example, two strings of diameters 1:2 will have vibration rates of 2:1.

4. For a given string the vibration frequency varies inversely as the square root of the density

$$N:N_1::\sqrt{D}_1:\sqrt{D}.$$

For practical purposes 3 and 4 are frequently combined into one statement, 5.

5. For a given string the vibration frequency varies inversely as the square root of the mass per unit length of the string.

For example, one piano string has a mass of 0.0016 lb. per foot, while another string has a mass of 0.16 lb. per foot. Then their vibration rates are as $\sqrt{0.16}:\sqrt{0.0016}$

$$N:N_1::\sqrt{0.16}:\sqrt{0.0016}$$
$$N:N_1::0.4:0.04$$

The absolute vibration rate of any string may be found from the equation:

$$N = \frac{1}{2L}\sqrt{\frac{T}{m}}$$

where n is the frequency; L the length of string in feet; T the tension in pounds multiplied by 32, and m the mass in pounds per foot of length.

A steel string 3 ft. long, weighing 0.01 lb. per foot and stretched by a force of 40 lb. will have a frequency of 59.6±

$$N = \frac{1}{2 \times 3}\sqrt{\frac{40 \times 32}{0.01}} = 59.6\pm.$$

The quality of the tones produced by a piano is determined in part by the position of the hammer, which is placed about one-eighth or one-ninth the distance from the end, and by the shape and hardness of the hammer.

The tonal quality when a melody note is struck depends upon the mass of other tones then existing from other keys previously struck and sustained, and it depends upon the length of time each of these tones has been sounding It is evident that not only does a piano give great variety of tone by various degrees of hammer blow, but there is possible an almost infinite variety of tone quality in combinations of notes struck at intervals of a few hundredths of a second.[1]

99. The Violin, Mandolin, and Guitar.—These instruments have sets of strings of slightly different lengths and sizes and wooden bodies to give the necessary intensity to the tones.

There are four strings on the violin tuned to fifths. The other notes are obtained by pressing the strings against the finger board and so shortening the strings. On some stringed instruments small raised strips called "frets" are used, indicating the point for shortening the strings to produce the notes desired. The frets make the instrument easier to play, but they have certain disadvantages. If one string is out of tune all the notes produced on it are out of tune.

The characteristic quality of the violin is due largely to the rather complete set of harmonic overtones which are present as a result of the lightness and flexibility of the so-called catgut strings. These strings are really obtained from the

[1] MILLER; "The Science of Musical Sounds."

intestines of lambs. The wrapping of one of the strings with fine wire keeps its flexibility, and gives the added mass necessary for the low tones.

100. Wind Instruments.—Organ pipes are the simplest of the wind instruments. They are made up of two parts—a vibrator and a resonator. There are two types of organ pipes: the flute pipes, in which the vibrations are produced by a stream of air passing over an edge, and reed pipes, in which the vibrator is a thin strip of metal. Both types may be of the open or closed kind. The construction of a flute pipe is given in the figure.

FIG. 59.—Open pipe.

The lower end has a mouth or embouchure much like a whistle. The air forced from the bottom escapes through a narrow slit against an edge just opposite. The upper part of the pipe is the resonator and may be either open or stopped. Its function is to reenforce the sound produced at the mouth.

If the resonator part of the pipe is absent and air is forced into the pipe, a soft whistling noise is heard, but when the resonator of proper shape and size to reenforce the vibrations is in place, a strong clear note is produced. In flute pipes the resonator is the chief factor in determining the pitch of the tone produced.

Reed pipes have a metal tongue which produces the vibrations. In the free reed pipe the metal tongue riveted at one end and free at the other, vibrates in an aperture. Cabinet organs, harmonicas, and accordions are of this type.

In the striking reed pipes the tongue is a little larger than the aperture. The tone is stronger and more penetrating. They are found in tin horns, in the clarinet and in some stops of pipe organs.

101. The Pipe as a Resonator.—Consider a closed pipe, CD, and let AE be one prong of a tuning fork in a position ready to move downward. As it moves, the air is compressed before it and this compression moves down the pipe CD. When it reaches D, the compression is reflected back and if

the pipe is just one-fourth of a wave-length for the given fork, then when it reaches C, it has travelled one-half of a wave length and the fork has reached A', having made one-half of a complete vibration. The fork returning toward A will send a rarefaction down the tube and the compression which reached C will be reflected back as a rarefaction. The motions of the fork and air in the tube agree and the tube will give out a sound of the same pitch as that of the fork. This is the resonance phenomenon.

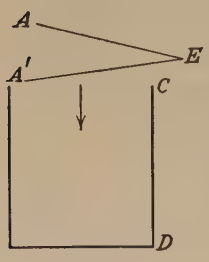


FIG. 60.

In a closed pipe there is always a node or place of minimum motion at the closed end and a loop or antinode, place of maximum motion, at the open end. In the open pipe acting as a resonator there are antinodes at each open end.

102. Overtones in Organ Pipes. *The Closed or Stopped Pipe.*—When the length of the pipe is one-fourth the length of the wave produced, the pipe is giving its fundamental or lowest note. But other vibrations can be produced, subject only to the condition of a node at the closed end and an antinode at the open end. A little consideration will make it evident that a closed pipe can resonate to notes which are as 3, 5, 7, etc., times the frequency of the fundamental, or to the odd overtones.

The Open Pipe.—The length of an open pipe when sounding its fundamental is one-half the length of the wave produced. Such a pipe can resonate to notes whose frequency is 2, 3, 4, 5, etc., times that of the fundamental note.

The middle C note, 256 vibrations per second, has a wave length of:

$$1{,}128 = 256 \times wl, \text{ at } 70^\circ \text{ F.}$$
$$wl = 4.4 + \text{ ft.}$$

Therefore, a closed pipe 1.1 ft. long will resonate to this note. Also notes whose frequencies are 768, (3×256) and 1,280 (5×256) will be reenforced by such a pipe.

For the same note the open organ pipe would be 2.2 ft. long, and it would resonate for frequencies 2, 3, 4, etc., times 256.

The figures show the position of the nodes and antinodes in open and stopped organ pipes for the fundamental and the first two overtones.

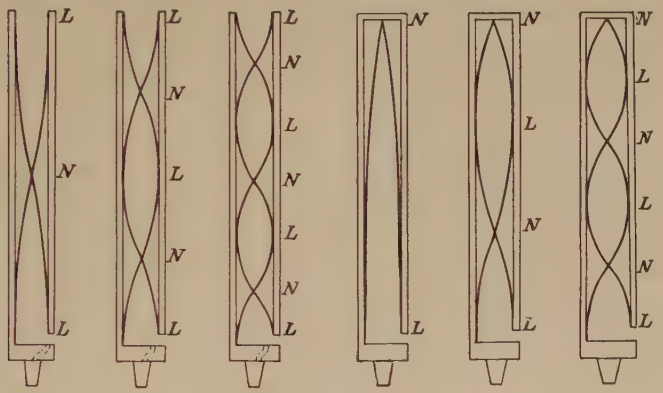


Fig. 61.

103. The Voice.—The mechanism for the voice is located at the top of the trachea. This position is marked by the Adam's apple. There are two thin membranes, the vocal cords, one on each side of a slit. In breathing, these cords are loose, but in speaking the muscles bring the membranes nearly together so that the air from the lungs passing through the narrowed opening causes the cords to vibrate. The pitch of the voice for a given person depends upon the muscular tension of the cords. The intensity of the voice depends upon the force with which the air is forced through the slit and upon the position of the mouth and throat. Nose, throat, and mouth, by changing shape and size, cause the different tonal qualities.

The range of the human voice is very much less than that of any musical instrument. For ordinary voices it is not over two octaves. Two and a half octaves is a large range. Galli-Curci's range is from B flat to high F, two and one-half octaves.

104. The Phonograph.—The phonograph was invented by Edison in 1877. In the original form the record was made on a sheet of tin foil placed over a spiral groove on a metal cylinder.

In making a record, a disc of soft wax is first filled with grooves, then a needle to which a vibrating diaphragm is attached is made to move in the grooves. The diaphragm is placed at the small end of a horn and the sounds striking against the diaphragm cause the attached needle to cut into the disc as it is moved around uniformly, thus making a record of the sound waves.

If now the needle is allowed to run in the grooves so cut, it will be thrown into vibration and these movements causing the disc or diaphragm to vibrate will produce the original sounds. The original soft-wax disc record is copper plated, the plate giving a duplicate of the wax impressions. Duplicates of this copper plate are used to stamp the records in some material which is kept warm and plastic but which on cooling becomes hard.

Some of the common ingredients used in making phonograph records are mud, China clay, talcum powder, coloring matter, barium, asphalt, cotton flock, and shellac. Edison records are made of a cheap pulp, covered with a thin layer of condensite.

There are two types of recorders. One type, the "hill and dale" method, makes the impressions on the disc by up and down movements of the needle. The Pathe and Edison phonographs are representative of this method. The "lateral cut" method records the sounds by a side to side movement. The Victor and Columbia phonographs are examples of this method.

The sound box is, perhaps, the most important feature of the phonograph. It consists of three essential parts: the needle, the needle bar and the diaphragm. The needle and needle bar form a lever with the fulcrum on the rim of the sound box. The vibrations of this lever transmit the vibrations in the sound line of a record to the diaphragm which impresses these movements on the air in the tone arm and horn.

There are two types of needles, the steel and fiber, and the diamond and sapphire needles.

The tone arm sends the sound waves, weak in intensity, to the horn. The function of the horn is to increase the sound

intensity. A perfect horn would send out sound waves of the same identical quality as those which were engraved on the original record. No horn probably will ever be made that will do this, but one of the differences between different makes of phonographs is the completeness with which the horn produces the original tonal qualities in the record.

Study Exercises

1. During a thunder storm the time between the flash of lightning and the thunder clap was 15 sec., but 5 min. later the time between the two was but 5 sec. How fast was the storm approaching?
2. Is the velocity of the bullet in modern firearms greater than the velocity of sound?
3. On a day when the temperature was 80° F. the sound of a locomotive whistle was heard 10 sec. after the steam of the blowing whistle was seen. How far away was the train?
4. If your ordinary speaking voice will carry 200 ft., how much additional energy must be put into it in order to carry 600 ft.?
5. What evidence does a band marching down the street away from you give that notes of low and high pitch travel with the same velocity?
6. If the pitch of your voice is 512, what is the wave length sent out when the temperature is 70° F.?
7. If the lowest note on a given piano has a wave length of 34 ft., what is its pitch?
8. Construct a diatonic scale for the key of G.
9. A given violin string gives the E above middle C for its fundamental. What will be the relative lengths of the strings to give the major chord?
10. The middle C string of a piano was flat by 3 vibrations per second when under a tension of 64 lb. What was the tension when the tuner had brought the string up to 256 vibrations?
11. What will be the length of open and closed organ pipes to give a major chord, starting with C = 256?
12. An open organ pipe is 16 ft. long. When the temperature is 70° F., what is the pitch of the sound produced?

Suggested References

1. Miller, "The Science of Musical Sounds."
2. Zahn, "Sound and Music."
3. Bragg, "World of Sound."

HEAT

CHAPTER X

TEMPERATURE

INTRODUCTION

Before taking up the study of temperature it may be well to make a brief answer to the question, "What is heat?" Heat is one of the many forms of energy, and the effects which bodies experience as they gain or lose this energy, are called heat effects. Temperature is one of these effects. We use the word "heat" frequently in place of heat energy and speak of giving heat to a body or of withdrawing heat, or of a source of heat, where it is obvious that heat energy is what we have in mind. A flow of heat then is merely the transference of energy.

105. Temperature.—The words "hot" and "cold" refer to a class of sensations which come through the sense of *temperature.* A hot body is the source of an influence which affects the sense of temperature just as a luminous body is the source of an influence which affects the sense of sight.

Our temperature sense is located in small "warm spots" and "cold spots" on the surface of the body, sensitive, respectively, to temperatures above and below that of the skin (at whatever temperature it may happen to be) and together averaging about 12 to each square centimeter of surface. When these points alone are excited, we ourselves feel hot or cold, but when they are excited simultaneously with the more sensitive pressure or touch spots, we are informed in regard to the hotness or coldness of the object touched. The response of these temperature spots is at first very quick, but falls rapidly to a small value or to zero if the stimulus is continued. What bather in the ocean has not felt the awful and sudden sensation of intense cold on the first plunge, yet each succeeding dip decreased the suffering though the intensity of the

stimulus remained constant. The hot bath water gradually comes to the proper temperature for our hand held in it, only to be seemingly suddenly increased in temperature as we step into the tub. The temperature of the skin can be altered considerably, if the change takes place slowly without the hot or cold spots giving any warning. The student often makes the sudden discovery late in the evening that the fire is out and that she is very cold.

A medium temperature which affects the warm spots on a cold hand may affect the cold spots on the warm hand. A familiar example is to take three cups of water, one at the temperature of the body, *A*, one colder, *B*, and one hotter, *C*. Hold one hand in *C* and the other in *B* for a few seconds, then put both hands in *A*. The water in *A* will be cold to the hand that has been in *C* and warm to the hand that has been in *B*.

The temperature sense also gives untrustworthy results when, for example, the hands or bare feet are placed on the rug and on the bare floor. The cork handle of the bicycle in winter seems warmer than the metal handle bar.

That the temperature sense is a skin effect is shown by the feeling of extreme heat which accompanies free perspiration while a clinical thermometer shows the bodily temperature to be little or no higher than usual.

106. Temperature Defined in Two Ways.—(*a*) Temperature may be defined as the degree of hotness. (*b*) Temperature may be defined as the condition of a body which determines the *direction* of the flow of heat between it and another body in contact with it.

The first definition finds illustration in the familiar practice of putting a wet finger on the hot flatiron, the hand into the oven to test its hotness, or the piece of potato or bread into the lard to determine its hotness for frying.

The second definition, where the idea of the direction of flow of heat is prominent, is illustrated by the flow of heat from the hot coffee up into the handle of the silver spoon, the use of holders in handling hot objects decreasing the rate of flow, the old-fashioned hot soap stone as a foot warmer, and

the modern use of the stone in the fireless cooker. In all these cases the direction of the flow of heat indicates the *relative* temperature of the body.

107. Measurement of Temperature. — Our bodily sensations are evidently not reliable measures of temperature. For measuring temperature some of the many heat effects are used, as the expansion of substances, the melting, boiling, and solidifying points of substances, etc. These effects can be used to better advantage because there is a quantitative relationship between the effect and the temperature. The most generally used effect is that of the expansion of a solid or liquid, and the mercury thermometer is the most common instrument for making temperature determinations.

108. Temperature Scales.—Two temperature scales are in common use, the Fahrenheit and the Centigrade. The two fixed points, the melting point of ice and the boiling point of water, under a pressure of 760 mm. of mercury, are 32° F., 0° C. and 212° F., 100° C., respectively.

The melting point temperature is found by placing the bulb in finely cracked ice. The boiling point temperature is found by placing the bulb and the stem of the thermometer in the vapor of boiling water. Since the boiling point is dependent upon the atmospheric pressure, to compare the boiling point on the thermometer with the true boiling point at the time of the experiment it is necessary to know the relationship between the boiling point and the atmospheric pressure and to know the barometer reading.

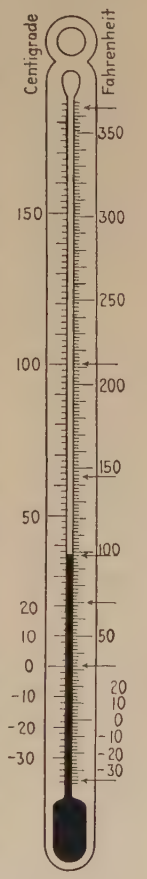


FIG. 62. — Centigrade and Fahrenheit scales.

This relationship for the two scales is given by the equations below:

True boiling point = 100° C. -0.0375 (760 − barometer reading in millimeters).

True boiling point = 212° F. −0.0675 (760 − barometer reading in millimeters).

A change in the barometer of 27 mm., approximately, will cause the boiling point of water to be raised or lowered 1° C.; while the change of 1° F. in the boiling point on the Fahrenheit scale is produced by a barometer variation of approximately 15 mm.

A thermometer, when placed in the vapor of boiling water, the barometer reading being 73 cm., read 99.4° C. Was this the correct temperature?

$$\text{True boiling point} = 100° - 0.0375(760–730).$$
$$= 98.875° \text{ C.}$$

A thermometer read 212.5° F. when in steam, and the barometer stood at 767.4 mm. Was this the correct temperature?

$$212.5 = 212 - 0.0675(760–767.4).$$
$$-0.0675 \times (-7.4) = 0.499+$$
$$212 + 0.499 + = 212.5.$$

The table below shows the relation between the altitude, average barometer reading, and the boiling point of water.

Altitude	Steam temperature		Average barometer readings	
	Degrees Centigrade	Degrees Fahrenheit	Millimeters	Inches
Sea level	100	212	760	29.9
2,000 ft	97.9	208.3	706	27.8
4,000 ft	95.9	204.6	655	25.8
6,000 ft	93.9	201.1	610	24.0
8,000 ft	92.0	197.6	526	22.3
14,408 ft. (Mt. Rainier)	88.0	190.4	436	17.17

Questions

1. From government reports or a local barometer find the usual variation of the barometer for the summer or winter months. How much

on the average is the boiling point of water changed? Is it on the average changed more in the summer or in the winter months?

2. Are any cooking operations carried on in the home or in the Home Economics laboratory where this change needs to be taken into account?

3. A change of 1 in. in the barometer will change the boiling point how many degrees on the Fahrenheit scale?

109. Conversion from One Scale into the Other.—Since 100° on the Centigrade scale equal 180° on the Fahrenheit scale (212° − 32°), one Centigrade degree = $\frac{9}{5}$ Fahrenheit degree and one Fahrenheit degree = $\frac{5}{9}$ Centigrade degree.

To express a temperature in Centigrade degrees in Fahrenheit, we must remember that 0° Centigrade corresponds to 32° F. The equations for transformation are then easily understood.

$$F. = \frac{9}{5} C. + 32.$$
$$C. = \frac{5}{9} (F. - 32).$$

Illustrative Problems

1. Change 20° C. to Fahrenheit. Since 1° C. centigrade is the equivalent of $\frac{9}{5}$° F., the 20° C. are equivalent to 20 × $\frac{9}{5}$ or 36° on the Fahrenheit scale. But this is *not* the *reading* on the Fahrenheit scale because the melting point of ice on the Centigrade scale from which the 20° was read is zero, and the same point on the Fahrenheit scale is 32 and the temperature on the Fahrenheit was 36° *above* the common point. Hence, the reading on the Fahrenheit scale is 32 + 36 or 68°.

2. Change 98.6° F. to Centigrade. The reading on the Fahrenheit scale indicates *not* a temperature of 98.6° above the melting point of ice, but a temperature of only (98.6 − 32) or 66.6° above the common point. Since each of these degrees is equivalent to $\frac{5}{9}$ of 1° C., the 66.6° are equivalent to 66.6 × $\frac{5}{9}$ or 37° on the centigrade scale. Since the common point on the Centigrade is 0°, the reading on this thermometer is 37°.

Study Exercises

1. If a room thermometer reads 68° F., what is the temperature reading on a Centigrade thermometer?

2. Hot coffee is about 140° F. What is its temperature on the Centigrade scale?

3. The food chamber of a good refrigerator should be at a temperature of about 7° to 10° C. What are the corresponding Fahrenheit values?

4. Ice cream has a temperature of about 17° F. Give its Centigrade value.

5. Two thermometers gave as the temperature for a cold morning −4° F. and −20° C. Did they indicate the same temperature?

6. Milk is pasteurized by heating it to 160° F. What temperature on the Centigrade scale corresponds to this?

110. Limits of Mercury Thermometers.—Since mercury freezes and boils, these temperatures evidently are the extreme limits of the use of these thermometers. The range, therefore, of the ordinary mercury thermometer is

−40° C. to 357° C.
−40° F. to 675° F.

Question

1. Is there a need in the home for measuring temperatures lower or higher than the limits of a mercury thermometer?

Fig. 63. Clinical thermometer.

111. Clinical Thermometers.—This thermometer is used for taking the temperature of the human body. It is a mercury-in-glass thermometer (Fig. 63) and differs from the ordinary thermometer in having a narrow constriction in the capillary tube and usually a lens front to magnify the very small mercury thread. When the thermometer cools, the mercury thread breaks at the point where it is constricted, leaving the column in the tube as it was at the highest temperature while in contact with the body. Thus, the correct temperature of the body may be found after the instrument has been taken from the mouth. To unite the mercury columns again, the thermometer must be given a jar or jerk. In the mouth, rather than against the dry skin, is the better place to take the temperature because the moisture lessens the time necessary for the instrument to acquire the bodily temperature. In the mouth of a patient most clinical thermometers will come to a steady state ready for a reading within a minute or two. The "normal temperature" of the body does not have a fixed value. It may differ by as much as 2° F. in a day. The temperature is usually lowest in the early morning and highest in the late afternoon. Such factors as age, sex, food, temperament, and occupation also influence the

body temperature. The so-called normal temperature is taken as 98.6° F. (37° C.).

Since an incorrect clinical thermometer is worse than none, it is wise to buy only those furnished with individual certificates by the maker or by the Bureau of Standards at Washington, giving the errors, if any, of the thermometer.

112. Oven Temperature Indicators.—The ordinary oven temperature indicator uses two different metal strips or spirals riveted together, with one end of the strip rigidly fastened while the free end

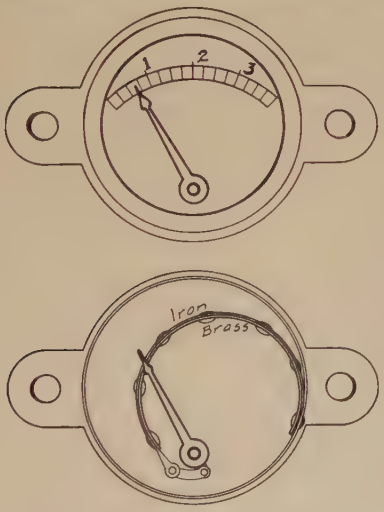


Fig. 64.—Oven temperature indicator.

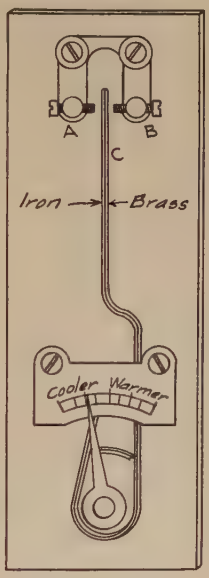


Fig. 65.—Section of a room thermostat.

is attached to levers which move a pointer over a scale. The two metals have a different thermal expansion and the change in temperature causes the strip, which is usually bent into the arc of a circle, to straighten out or to curl up. Thus the pointer moves in one direction for rising temperatures and in the opposite direction for falling temperatures. At present these metallic thermometers are neither very accurate nor constant in their readings (see **Art. 119**).

113. Room Thermostats.—These are generally of the same type as the oven indicators, but as the range of temperature variation is small, their readings are fairly accurate and constant.

114. The Lorain Regulator.—The Lorain oven heat regulator is perhaps the best known of the various oven regulators for gas ovens. The gas enters the device at I from the supply main. At the top of the oven is a copper tube T. When the temperature wheel W is turned toward higher temperatures the rod R is pushed to the right, causing the long lever, L,

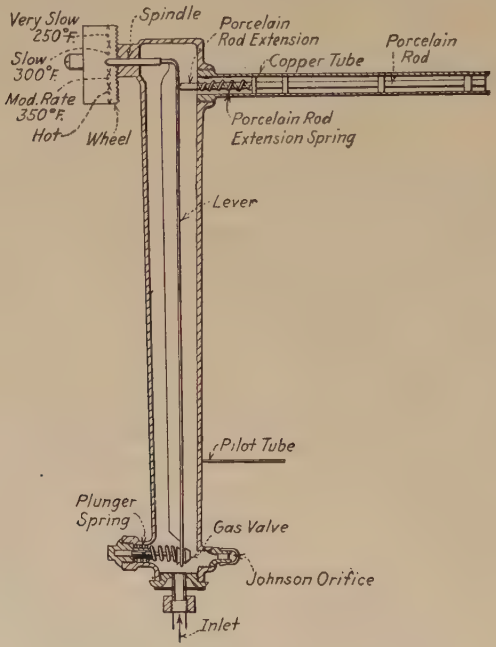


FIG. 66.—The Lorain oven heat regulator.

to rotate about its falcrum F, which is the end of a porcelain rod P in the copper tube and is pivoted to the lever. The lower end of the lever then pushes to the *left*, compressing the spring S, which opens the valve V, allowing gas from the mains to enter the oven burners through B. As the oven warms up the copper tube T expands more than the inner porcelain rod P, so the porcelain rod P moves to the right. As the porcelain rod is always pressing against the right end of the copper tube due to the spring H, the movement of P to the right moves

the lower end of the lever to the right, and the spring S then partly closes the valve V, thus decreasing the flow of gas to the burners. When the oven cools the actions are reversed, thus giving more gas to the burners. Such a device is a great saver of gas as well as giving rather close control of oven temperatures. A pilot flame is provided which will automatically light the burners if desired.

115. Testing of Thermometers.—(*a*) Corrections due to errors in the fixed point readings.

The ordinary chemical thermometers usually have incorrect scales; the errors sometimes are too small to take into account, but often they are too large to admit of even approximate temperature readings. A candy maker's thermometer was found to have an error of 13° F., which, of course, made it useless unless the error was known.

For the usual work in the home the testing of two fixed points, the freezing and the boiling points of water, is sufficient. Let us suppose a given thermometer, when tested as explained in **Art. 108,** reads 30° F. in the ice bath and 214.3° F. in the steam, the barometer at the time reading 75 cm. Then the error of the freezing point is 2° F. and, using the relationship given in **Art. 108,** the correct boiling point is 211.3° F., the error being 3° F. Both of these errors affect all the temperatures read on the thermometer. To find the effect of these errors at any point on the thermometer, a curve can be plotted as shown below.

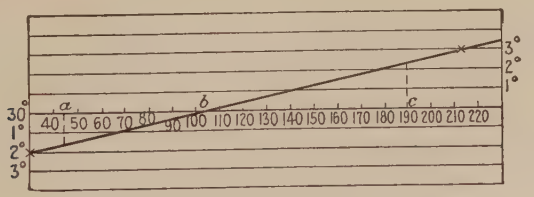


FIG. 67.—Correction curve for the fixed point errors.

At a the thermometer reads 45° F., the correction taken from the curves is 2°, hence the correct temperature at a is not 45° but 47°. At b the two errors neutralize each other

and at this one point only the thermometer reads the correct temperature. At *c*, the error obtained from the curve is 2.3° and the correct temperature is not 190° but 186.7°. It will be noticed that when the reading at a fixed point is *less* than the correct temperature the thermometer readings are too small and the corrections are *added*, while the reverse is true for a reading at a fixed point *greater* than the correct temperature.

(*b*) Corrections due to irregular bore in the thermometer and to emergent stem:

In some experimental work it is necessary to know temperatures to one-fifth or one-tenth of a degree and then the thermometer must have its bore calibrated. The best and easiest way to do this, if the laboratory has one thermometer of known calibration, is to tie the two thermometers, the calibrated and the uncalibrated, together with their bulbs opposite each other, then immerse them in a well-stirred water bath whose temperature is either constant, or, if changing, is slowly rising. Now take simultaneous readings of the two at say 5° intervals for the range through which the thermometer is to be used. The following data and curve will help to make clear the use of the calibration data thus obtained:

Calibrated thermometer	Readings on uncalibrated thermometer	Error	Correction
40.3	40.0	−0.3	+0.3
45.6	45.7	+0.1	−0.1
50.1	50.0	−0.1	+0.1
55.0	55.3	+0.3	−0.3
60.2	60.1	−0.1	+0.1
65.4	65.2	−0.1	+0.2
70.0	70.0	0.0	0

If the thermometer reads 55°, the curve shows the error to be +0.3°, and the correction is to be subtracted; hence the correct reading is 54.7°.

For finding the correction for fixed-point errors and bore errors, the two errors must be added algebraically.

(*c*) Correction for emergent stem:

The correction for emergent stem becomes of moment in high-temperature work where only a part of the mercury in the stem is exposed to the high temperature. For example, a chemical thermometer used in candy making, where only a few degrees of emergent mercury are in the candy and the rest are in the air at a temperature below that of the candy, or a long thermometer put into the top of an oven, the greater part of its length being out in the air. In all cases of this kind, accurate work requires a correction of the thermometer reading. The relative coefficient of expansion for mercury in

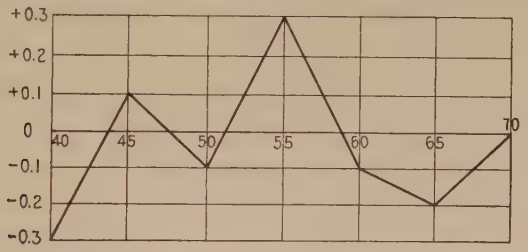


FIG. 68.—Correction curve for errors of bore.

Jena normal glass is 0.00016. If $n°$ of the mercury filament are outside the oven, then the difference in the height of the filament for a difference of 1° C. will be $0.00016n$. Let t be the mean temperature of the filament outside and T the temperature as read on the thermometer, then the correction to be *added* to the indicated reading is

$0.00016n(T - t)$ correction in degrees Centigrade.

$0.00009n(T - t)$ correction in degrees Fahrenheit.

A given candy thermometer read 120° C., 80° of the filament were outside the bath, and the mean temperature of this emergent filament as shown by another thermometer placed with its bulb midway of the emergent filament was 40° C. Then

$0.00016 \times 80(120 - 40) = 1.02°$ C. = correction to be added.

A thermometer in the top of an oven read 420° F. and 200° were outside. The mean temperature of the filament outside was 80° F. Then

$0.00009 \times 200(420 - 80) = 6.1°$ F. = correction to be added.

The correct temperature inside the oven was 426.1° F.

116. Some Temperatures Used in the Home.

	Degrees Centigrade	Degrees Fahrenheit
Freezing mixture, 3 parts ice, 1 part salt	−21	−6
Vanilla ice cream:		
Soft	−8	18
Medium	−9.4	15
Hard	−13	9
Lard and butter melt at about	33	92
Hot-water radiator about	76	170
Hot air from floor register, very variable	55 to 76	130 to 170
Tea or coffee for drinking	50 to 62	120 to 140
Sugar Sirups:		
For sirup, 2.75 lb. per quart	104	219
For fondant candies	113	236
For fudge candies	115	240
For taffy candies	149	300
For clear brittle	154	310
For almond or walnut brittle	157	315
Oven baking:		
Slow oven	94 to 150	200 to 300
Medium oven	150 to 205	300 to 400
Quick oven	205 to 288	400 to 550
Pastry oven	232 to 288	450 to 550
Steam from boiling water:		
Under a pressure of 11.02 lb., or ¾ atmosphere	92	197.7
Under a pressure of 14.7 lb. or 1 atmosphere	100	212
Under a pressure of 20.0 lb	108.7	228
Under a pressure of 25.0 lb	115.5	240.0
Under a pressure of 30.0 lb	121.2	250.3
Pasteurizing milk (flash process)	71	160
Pasteurizing milk	63	145
Soft solder melts	185	365
Aluminum melts	659	1218
Blue gas flame	1050	1922
Carbon filament lamp (3.1 watts per candle)	1950	3550
Tungsten filament (1.0 watt per candle)	2100	3800

* * * * * * * * * * * * * * * * * * * *

The lowest conceivable temperature is −273° C. or −459.4° F.

Some Suggested Laboratory Exercises

1. Determination of the errors of a thermometer.
2. Study of oven, candy and clinical thermometers.
3. Temperature and pressure relations.
4. Experimental determination of oven temperatures in cooking operations.
5. Temperature of flatirons and fireless cooker radiators when in use.

REVIEW SUMMARY

Heat is a form of energy, energy of the vibrating molecules.

Bodily sensations of temperature are unreliable.

Temperature is the degree of hotness or the thermal condition which determines the direction of flow of heat between two bodies in contact.

Temperature is determined by one of the heat effects, expansion of mercury being the most common effect used.

Fixed points on a thermometer are freezing point of water, or melting point of ice, and the boiling point of water under a pressure of 76 cm. of mercury.

Degrees Centigrade are converted into Fahrenheit reading by the relation: F. = $\frac{9}{5}$ C. + 32.

Fahrenheit readings are converted into degrees Centigrade by the relation C. = (F. − 32)$\frac{5}{9}$.

Limits of temperature with a mercury thermometer are determined by the freezing and boiling points of mercury.

Temperature indicators are based on the difference in expansion of metals.

Methods of correcting for thermometer errors due to: (*a*) fixed points, (*b*) irregular bore, (*c*) emergent stem.

CHAPTER XI

EXPANSION

117. Heat Effects.—Whenever heat is applied to a body, one or more of the following effects take place:

1. Rise of temperature.
2. Expansion. Change in length and volume.
3. Change of state, fusion or vaporization.
4. Increase of pressure on the walls of the containing vessel.
5. Change in physical characteristics.

In the chapter on Temperature we have already made direct use of the first two of these effects and we are now to study expansion somewhat more in detail.

With a few exceptions, solids, liquids and gases expand when heated and contract when cooled. Although the expansion is too small to be directly visible, the results of expansion are very evident. The teakettle too full overflows when heated, the empty pan on the stove bulges up, the fruit jar may break on the first contact with the cooked fruit, the warmed neck of the bottle allows the tight stopper to be removed, the expanding gas helps to make the baking bread lighter.

118. Coefficients of Expansion.—Experiments show that solids and liquids have expansions which are characteristic of the substance, but that all gases have very nearly the same coefficient of expansion. In order to compare the expansions of different substances it is necessary to know the coefficient of expansion for each.

If it is the change in length that is being considered, then the coefficient of linear expansion must be known.

Let L_0 be the length of the body at temperature t_1 and L_t be its length at t_2, then

$L_t - L_0$ = the expansion of the body for $t_2 - t_1$ degrees change in temperature.

$\frac{L_t - L_0}{L_0}$ = the expansion of unit length of the body

and this quotient divided by $t_2 - t_1$ will be the expansion of *unit* length for *one degree* change in temperature. This gives a value that is characteristic of the substance and it is called the "coefficient of linear expansion."

If this coefficient is represented by a then

$$a = \frac{L_t - L_0}{L_0(t_2 - t_1)}, \text{ or } L_t = L_0[(1 + a(t_2 - t_1).]$$

If now the change in volume is being considered, the cubical coefficient of expansion, say, k can be given in a similar equation.

$$k = \frac{V_t - V_0}{V_0(t_2 - t_1)}, \text{ or } V_t = V_0[(1 + k(t_2 - t_1).]$$

Will the value of a depend upon the unit of length used? Will k? If the difference in temperature $(t_2 - t_1)$ is in degrees Centigrade or in degrees Fahrenheit, will the values of a and k be the same?

Illustrative Problems

1. A glass tumbler is 4.5 in. high at 60° F. What is its height at 160° F? The table gives the coefficient of expansion of glass as 0.000009 per degree Centigrade. The coefficient per degree Fahrenheit will be $0.000009 \times \frac{5}{9} = 0.000005$. Then

$$L_t = 4.5(1 + 0.000005 \times 100) = 4.50225 \text{ in.}$$

2. Five liters of water at 20° C. are heated to 100° C. What is the volume of the water?

$$V_t = 5(1 + 0.00043 \times 80) = 5.172 \text{ liters.}$$

3. The hot-water pipe from first floor to second floor is 10 ft. long at 60° F. and at 200° F. its length is 10.0084 ft. What is the coefficient of expansion of iron?

$$a = \frac{10.0084 - 10}{10 \times 140} = 0.000006 \text{ ft. per degree Fahrenheit per ft.}$$

$0.000006 \times \frac{9}{5} = 0.000011$ ft. per degree Centigrade.

4. The air outside a chimney is at 0° C. and the average temperature of the air in the chimney is 100° C. What is the weight of 1 cc. of air in the chimney? Assume 1 cc. of air at 0° C. weighs 0.0012 g. The volume of 1 cc. of air at 100° will be

$$V_t = 1(1 + 0.0036 \times 100) = 1.36 \text{ cc.}$$

This volume of air weighs 0.0012 g. Hence 1 cc. will weigh $\frac{0.0012}{1.36} =$ 0.000882 g.

Some coefficients of expansion per degree Centigrade (approximate):

	Linear	Cubical
Glass	0.000009	0.000027
Brass	0.000018	0.000054
Iron	0.000011	0.000033
Platinum	0.000009	0.000027
Aluminum	0.000023	0.000069
Pyrex glass	0.000003	0.000009
Ice	0.000051	0.000153
Porcelain	0.000004	0.000012
Mercury	.....	0.00018
Water	.....	0.00043
All gases, $\frac{1}{273}$ of volume at 0° C. or	.....	0.00366

119. Applications of Expansion and Contraction.—We are not concerned much in the home with the actual values of the coefficients, yet differences of expansion will explain many of the phenomena met with in our daily life.

Why should the full teakettle overflow when heated? The table shows that the expansion of water is over six times greater than the expansion of the aluminum kettle. When the hot liquid falls on the bottom of the fruit jar, the inner surface, receiving the temperature change first, expands more than the outer surface and the bottom is ruptured by the effect of these two different expansions. The table shows clearly why Pyrex, the new cooking utensil material, can be made rather thick yet not break when subjected to sudden temperature changes on one surface of the vessel. Its expansion being only about one-third that of glass, the two expansions, at the inner and outer surfaces are smaller and hence the Pyrex glass is strained less. A comparison of the expansion of the air

enclosed in pie crust dough under two different conditions, will disclose the reason for the suggestion that cold materials will produce lighter crusts.

Assume the air enclosed in one pie crust was 75° F. (24° C. approximately) and in the other crust 36° F. (2.2° C.) and that both pies are baked in an oven at 425° F. (218° C. approximately). The expansion of the air in the two cases would be: $(218 - 24) \times 0.0036 = 0.6984$ cc. for each cubic centimeter of air; $(218 - 2.2) \times 0.0036 = 0.7763$ cc., or 11+ per cent greater.

FIG. 69.—Balance wheel.

Granite vessels after frequent use sometimes have the granite come off in flakes due to the weakening of the cohesion between the granite and the iron because of the different expansions of the two. The metallic oven thermometers as well as the thermostat described in the chapter on Temperature are illustrations of the effect due to differences in expansion. If brass and iron are the two metals of equal length riveted together, the compound bar will, on being heated, become curved, with brass on the *outside*, the longer curve.

The balance wheel of a watch and the pendulum of the clock control in part the time-keeping qualities of these timepieces; but both tend to make the timepieces run slower when their temperatures are raised and faster when lowered. The means used to make these two automatically correct for these effects is an interesting application of expansions. The rim of the balance wheel is made up of two strips of metal, the inner one of steel and the outer one of brass, fastened rigidly by screws. When the temperature rises, the free end of the rim curls inward, thus bringing part of the rim nearer the axis, which tends to compensate for the effect of the temperature rise which otherwise would move the rim, due to expansion, farther from the axis and decrease the time of rotation.

A change in temperature will tend to make the length of a pendulum change, with a resulting change in the rate of the clock. In the gridiron pendulum, the expansion of the rods in dark outline will tend to make the pendulum bob *B*

longer, while the expansion of the brass rods in light outline will tend to raise the bob. If the rods are properly arranged the lengthening effect of the dark rods can be counteracted by the shortening effect of the light rods. In the mercury pendulum, often seen in French clocks, the lengthening of the rod, lowering the center of the whole mass, is corrected by the expansion the mercury tending to raise the center of the whole mass.

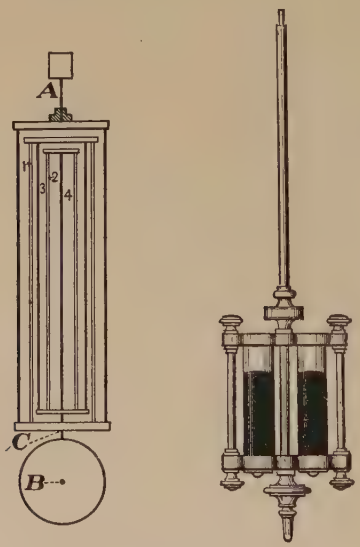


FIG. 70.—Gridiron pendulum and mercury pendulum.

120. Forces in Expansion.—Experiment shows that in order to increase the length of an iron bar 1 ft. long and 1 sq. in. in cross-section by 0.000196 ft., a force of 6,000 lb. will be required.

Now when such a bar has its temperature raised 24° F. it will expand so that its new length is 1.000196 ft. If the bar is to have its temperature raised 24° F., yet not increase in length, a force of 6,000 lb. must be applied to it. A cubic foot of water, for a temperature rise of 25° F., will expand to 1.01075 cu. ft. To prevent this expansion will require a force of 3,200 lb. per square inch.

The radiators used in fireless cookers frequently crack and sometimes even break into pieces when placed on the stove if water has been absorbed by them. The expansion force of the water is greater than the cohesive forces of the radiator. The waterbacks in kitchen ranges and the hot-water pipes in the hot-water heating systems have sometimes burst with serious results when some part of the pipe has frozen or become stopped. As soon as the fire was started, the water began to expand, and, as it could not move through the closed pipe, the force of expansion was applied to the walls of the pipe, soon becoming too great for the iron to stand, hence the pipe was ruptured.

121. Drafts in Chimneys.—If a gram of a substance be heated, its volume, due to expansion, becomes greater and hence the weight of the substance for a given volume is less. A cubic foot of air at 32° F. weighs, under normal conditions 0.081 lb., while at 100° F., 1 cu. ft. weighs 0.065 lb. The weight of any body is due to the attraction of the earth for it. The earth then will attract or pull down 1 cu. ft. of cold air with greater force than 1 cu. ft. of hot air. Imagine a condition as shown in the figure. The heavier cold air will exert a greater downward pressure on the column of hot air than the hot air exerts on the column of cold air.

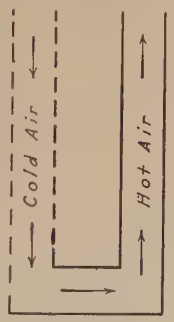


FIG. 71.—Air movements.

If we assume these columns to have volumes of 1 cu. ft. each, then the excess of pressure will be (0.081 − 0.065) = 0.016 lb. The result of this will be that the cold air will push the hot air up and then, in turn being heated and expanding, will be pushed up by more cold air, thus establishing an upward movement of the heated air and a downward movement of the cold air, or what is called a draft. This is evidently the explanation of the draft in chimneys, fireplaces, stoves, and heating systems.

The sketches will make clear the movement of the air in a chimney, a fireplace and a kitchen range.

Explain by the aid of a sketch the trouble that may result from:

1. A chimney too short.
2. A chimney on the outside wall of a house.
3. A too large chimney flue.

4. Two chimneys of different height or under different conditions, in communicating rooms. For instance, either chimney alone may draw well, but when one is working and a fire is started in the other it may smoke badly.

5. Presence of higher roofs or walls near by.

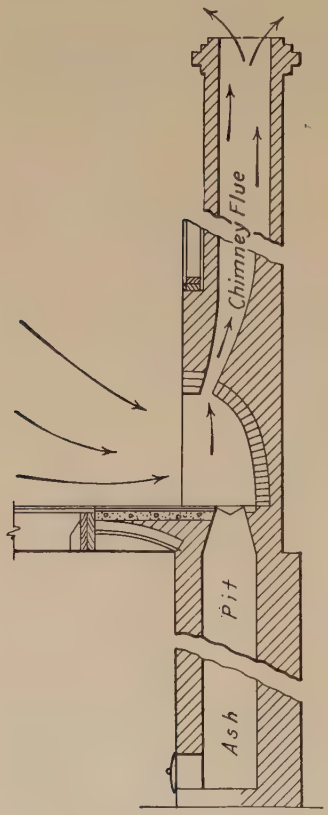


Fig. 72.—Fireplace and chimney.

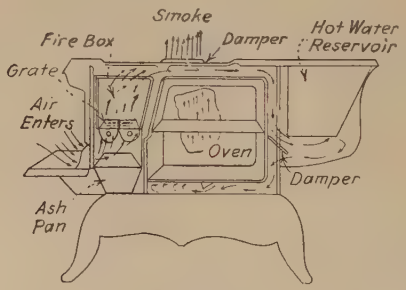


Fig. 73(*a*).

Fig. 73(*b*).

122. Peculiar Expansion of Water.—Most liquids expand continuously as their temperature is raised, or contract as it is lowered. But if a jar of water at 4° C. or 39.1° F. has its temperature either *lowered* or *raised*, it slowly *expands*. Water, then, slowly contracts as its temperature is raised

from 0 to 4° C. and at this temperature has the maximum weight per given volume. As the temperature rises above 4° C. the water expands. The effect this has in nature, on the surface freezing of lakes and rivers, can be illustrated by a tall jar of water with a piece of ice floating on it. A thermometer at the bottom of the jar and one just beneath the ice will both drop in temperature, but the one at the bottom will stop at 4° C., while the one at the top will fall to 0° C. If now the ice is removed, the top one will rise to 4° C. before the bottom thermometer changes, for, although the entire jar is being warmed, as long as there is water at 4° C. anywhere, it will sink to the bottom. Since water freezes only at 0° C. is it possible to freeze solid a jar of water?

Study Questions

1. The mercury thread in a thermometer falls at first when placed in hot water. Why?
2. Why do some kinds of wood crackle when they burn?
3. The zinc under a stove wrinkles when hot if the edges are nailed down. Why?
4. What objection is there to fastening rigidly the grate bars in a stove or furnace?
5. Why do apples swell when heated?
6. Can you suggest why a platinum wire, instead of some other metal, is sealed into the electric light bulb?
7. Do you think the hot-water or steam pipes in your home need to have some device for taking care of their change in length under different temperatures? Examine the system for any such device.
8. Why do cement walks have gaps left about every 15 to 20 ft. while the plaster wall does not?
9. If in making a cake the air enclosed in the dough is at 40° F. and the cake is baked in an oven at 350° F., what is the change in the volume of the enclosed air?
10. Will it help in removing the metal cover from a fruit jar to immerse the cover in hot water for an instant?
11. Explain why a drop of water on the hot lamp chimney produces such disastrous results.
12. If a pint can of soup is heated from 60 to 212° F., what is the change of volume of the soup? Assume expansion is the same as that of water.
13. Why does the bread curl up when it is being toasted?
14. Why do tall chimneys have the better drafts?

15. Explain why fireplaces sometimes smoke when the fire is first built. Why should a burning paper held in the chimney flue stop this first smoking?

16. What will be the effect on the fibers of soaking clothes in boiling water and then transferring them to warm water for washing?

17. Is the increase in the volume of the ice-cream mixture on freezing a true expansion effect?

18. If the zinc cover on a Mason jar is quickly raised in temperature 30° F., the diameter of the cover being 3.5 in. and the coefficient of expansion of zinc being 0.000016, find the increase in length of the circumference of the cover.

19. Five quarts of water are heated from 15 to 95° C. What is the volume of the hot water?

20. Why does the bottom of a sheet-iron frying pan bulge in when put on the stove empty?

21. Enameled gas-stove ovens should not be washed when hot. Why?

22. Is the increased size of the kernel of corn when popped due to expansion of the corn?

23. A window glass is 150 by 100 cm., say, at 70° F. What is its area when the glass is at 90° F.?

24. A cubic foot of air enters the furnace at 70° F. and leaves it at, say, 370° F. What is its volume?

25. The iron bars in the oven rack are 18 in. long at 65° F. What is their length when the oven is at 465° F.?

Some Suggested Laboratory Exercises

1. Study of expansion effects on granite ware of different grades. Repeated heatings and sudden coolings of the pans.

2. Coefficient of expansion of glass and Pyrex ware.

3. Study of the directions of air movements in a room and at a partly open door.

4. Rough quantitative tests of the forces in the expansion of air, steam, water.

REVIEW SUMMARY

Heat effects: temperature rise, expansion, change of state, increase in pressure, change in physical characteristics.

Coefficient of linear expansion. The ratio of the increase in length to the original length for a change of temperature of 1°.

Forces due to expansion—large.

Drafts in chimneys, stoves, etc.

Expansion of water. Maximum density at 4° C.

CHAPTER XII

QUANTITY OF HEAT

123. Heat and Temperature.—Joseph Black, a Scotch chemist and physicist, about 1760 was the first to draw a clear distinction between *heat* and *temperature*. Heat is a form of energy and temperature is the condition which determines the direction of the flow of energy or heat. A quart of boiling water and the stove lid may have had equal amounts of heat given to them, but the lid is at a much higher temperature; the cup of coffee and the coffee in the pot may be at the same temperature, but the amount of heat in the pot is much greater. A block of ice may have more heat than a red-hot ball of iron. There is evidently then no *fixed relation* between the temperature and the amount of heat in different bodies.

A mechanical analogy may help to bring out this difference. Two tanks of water in the attic may indicate on the gages in the basement the same pressure, but from this fact no statement can be made concerning the *amounts* of water in the tanks; but if the two gages read different pressures, the direction of flow of the water between the two tanks, if connected, can be stated. Temperature, then, is roughly analogous to pressure in liquids; each gives a knowledge of the direction of the flow without indicating in any way the amount of the flow.

Heat is regarded as a quantity, a something which can be handed on from one piece of matter to another, and we may properly ask *how much* heat is gained or lost by a body when there is a change in its temperature. Temperature may be considered as a quality or condition which varies from one body to another or in different parts of the same body.

We are observing, however, temperature, or temperature changes, and, in general, we assume *gain* of heat if the temperature rises or *loss* of heat if the temperature falls. Atten-

tion should be called to the fact that we do not at present have any clear, definite idea of the total amount of heat in a body, but what is measured is the amount of heat absorbed or given out by a body.

124. Heat Units.—Since heat is a form of energy it would be natural to expect that quantity of heat should be measured in energy or work units. But as no satisfactory energy unit is available, quantity of heat is generally measured in units, using as the factors, mass and temperature.

When any substance, as water, for example, is heated, the temperature of the body is raised, and the unit of quantity of heat that has come to be generally accepted is the amount of heat energy required to raise unit mass of *pure water* 1°. If the mass of water taken is 1 g. and the rise of temperature 1° C., then this unit quantity of heat is called the *calorie*. In books on food and nutrition, as well as in some chemistry texts, another unit is often used, the *great calorie*, or as it should be called, the kilo-calorie, a unit 1,000 times as large as the calorie. A British thermal unit is the amount of heat energy necessary to raise 1 lb. of water 1° F. Experiment shows that the amount of heat necessary to raise unit mass of water 1° is not a constant. The amount varies below the boiling point of water by as much as 1 per cent. Because of this fact the calorie or B.t.u. is not a constant unit and different temperature ranges are selected. The calorie is, perhaps, more accurately defined as the amount of heat necessary to raise 1 g. of water from 19.5 to 20.5 C. For all ordinary work the calorie as defined in the text is sufficiently accurate.

1 B.t.u. = 252 cal.
1 cal. = 0.00396 B.t.u.
1 kilo-calorie or great calorie = Cal. = 1,000 cal.

Illustrative Problems

1. Two quarts of water are heated from 62° to 212° F. How many B.t.u. were required? How many calories?

Two quarts of water weigh 4 lb., $212° - 62° = 150°$

$4 \times 150 = 600$ B.t.u.
$600 \times 252 =$ calories required.

2. If 100,000 cal. are required to do a given cooking operation, how many cubic feet of gas, 600 B.t.u. per cubic foot, will be necessary, assuming that only 50 per cent of the heat of the gas is used?

$$100{,}000 \div 252 = 397 \text{ B.t.u. approximately.}$$

Since 50 per cent of heat is wasted the gas burned must furnish 2×397 or 794 B.t.u.

So $79\frac{4}{600}$ or 1.32 cu. ft. will be consumed.

3. Is the kilo-calorie equal approximately to heat required to raise 1 lb. of water 4° F.?

One pound of water raised 4° F. requires 4 B.t.u.

Four B.t.u. equal 4×252 cal. = 1,008 cal. or since lb. = 454 g. approximately, and 4° F. = $\frac{20}{9}$° C. then $454 \times \frac{20}{9}° = 1008$.

125. Thermal Capacity.—If we should place a flatiron, an aluminum cup, a china cup, a silver spoon in boiling water and then place them successively in the *same* amounts of water at the *same* temperature, we would find that each mass of water was raised to a different temperature. Evidently each article held a different amount of heat, the *thermal capacities* of each were different. To compare their thermal capacities, we would need to divide the amount of heat they gave to the water by the temperature change in the body.

The following experimental data were obtained to illustrate the statements just made.

A 1,600-g. flatiron was transferred from water at 100° C. into 1,000 g. of water at 20° C. The temperature of the water was raised to 31.9° C. Hence, the iron lost and the water gained (31.9–20) 1,000 = 11,900 cal. Since the temperature of the iron changed 68.1° C., the amount of heat the iron can give out or absorb when its temperature is changed 1° is 11,900/68.1 = 174.7 cal. The thermal capacity of the flatiron is then 174.7 cal.

An aluminum cup weighed 200 g. and when it was transferred from water at 100° C. into 1,000 g. of water at 20° C., the temperature of the water was raised to 23.22° C. The heat lost by the cup and gained by the water was 3,220 cal. The temperature change of the cup was 76.78° C. Hence, the thermal capacity of the aluminum cup is 3,220/76.78 = 4.19 cal.

The thermal or heat capacity of a *body* is the amount of heat required to raise the temperature of the body 1° or the amount of heat the body gives out when its temperature is lowered 1°.

$$\text{Heat capacity of a body} = \frac{\text{heat gained or lost}}{\text{change in temperature}} = \frac{H}{t_1 - t_2}.$$

From the heat capacities of the flatiron and the aluminum cup we might be led to the conclusion that iron as a *substance* has a greater heat capacity than aluminum. To compare the heat capacity of the two substances, we must evidently consider *equal* masses. If we divide the heat capacity of the iron, 174.7 by its mass, 1,600 g., we obtain 0.109 as the number of calories taken in or given out when 1 g. of iron changes its temperature 1°. For aluminum we obtain 0.209 cal. These values are the heat capacities of the substances, iron and aluminum.

The heat capacity of a *substance* is the amount of heat required to raise *unit mass* of the substance 1° or the amount of heat given out when a unit mass is cooled 1°.

$$\text{Heat capacity of a substance} = \frac{\text{heat gained or lost}}{\text{change in temperature} \times \text{mass}} = \frac{H}{(t_1 - t_2)m}.$$

126. Specific Heat.—The heat capacities of all *substances* are compared with the heat capacity of water taken as unity. The *ratio* of the heat capacity of a substance to the heat capacity of water is called the "specific heat" of the substance or

$$\text{Specific heat} = \frac{\text{calories to raise 1 g. of substance 1° C.}}{\text{calories to raise 1 g. of water 1° C.}}$$

$$\text{Specific heat} = \frac{\text{B.t.u. to raise 1 lb. of substance 1° F.}}{\text{B.t.u. to raise 1 lb. of water 1° F.}}$$

Numerically, specific heat equals the *heat capacity* of the *substance.*

The following table gives the specific heats of some common substances:

Water	1.00	Silver	0.06	Glass	0.195
Steam	0.46	Tin	0.05	Soapstone	0.20
Ice	0.50	Aluminum	0.21	Crockery	0.20
Air	0.24	Copper	0.095	Brick	0.20
Alcohol	0.60	Brass	0.09	Salt	0.17
Olive oil	0.32	Nickel	0.10	Lard	0.35
Mercury	0.03	Iron	0.11		

The following are average specific heat values of some foods and of the body.

Veal	0.70	Milk	0.90	Chicken	0.80
Eggs	0.76	Cream	0.68	Human body	0.83
Potatoes	0.80	Lean beef	0.77		

With a few exceptions, water has the highest specific heat of all substances.

Illustrative Problems

1. An aluminum dish was raised 1° C. by the addition of 100 cal. of heat. What was the thermal capacity of the dish?

From definition of the thermal capacity of a *body* the thermal capacity of the dish was 100 cal.

2. If the dish in Problem (1) had a mass of 500 g., what is the thermal capacity of aluminum?

From definition of thermal capacity of a substance, $^{100}/_{500} = 0.2$, the thermal capacity of aluminum.

3. In Problem (1) the thermal capacity of the dish was found to be 100 cal. How many grams of water would have the same capacity? Evidently 100 g. since 100 cal. would be required to raise the water 1° C. The 500-g. dish is said to have the thermal capacity of 100 g. of water or its *water equivalent* is 100.

4. A 6-lb. flatiron is heated to 450° F. How much heat will it lose when cooled to room temperature 70°?

Since the specific heat of iron is 0.11, 1 lb. of iron cooling 1° will give up 0.11 B.t.u. In cooling 450° −70° or 380°, 1 lb. will give up 0.11 × 380 or 41.80 B.t.u. So the 6-lb. iron will give out 41.8 × 6 or 250.8 B.t.u.

5. Which is the better bed warmer, a hot-water bottle containing 1 qt. (2 lb.) of water at 200° F. or a 5-lb. brick at 200° F.? Let us compare the two when they have cooled to 100° F.

Then for the hot-water bottle

$$2 \times 100 \times 1 \text{ (specific heat)} = 200 \text{ B.t.u. given up.}$$

For the brick

$$5 \times 100 \times 0.2 \text{ (specific heat)} = 100 \text{ B.t.u.}$$

6. Five pounds of water at 60° are mixed with 20 lb. of water at 160°. What is the resulting temperature? Let X be the final temperature. The cold water will rise in temperature and the hot water will fall and the gain in heat by the one must equal the loss of heat in the other. Therefore,

$$5(X - 60) = 20(160 - X),\ X = 140° \text{ F.}$$

7. What is the specific heat of copper if the following data is obtained: mass of the copper 200 g., original temperature 100° C., final temperature 80° C., the water in which it was placed was at 70° C. and was raised to 80° C., the mass of water was 35 g., the tin pan holding the water had a mass of 60 g. and a specific heat of 0.05?

Since no heat energy is assumed to be lost in the operation we will find the heat gained and the heat lost. The water gains $35(80 - 70)$ cal., the tin pan gains $60(80 - 70)0.05$ cal., and all this heat was given up by the copper. The heat lost by the copper is $200(100 - 80)$ times specific heat of copper or X. Therefore,

$$200(100 - 80)\ X = 35(80 - 70) + 60(80 - 70)0.05.$$
$$4{,}000X = 350 + 30.$$
$$X = 0.095.$$

8. A 4-lb. aluminum kettle contains 8 lb. of water at 62° F. and the water is raised to 212° F. How much heat was given to the kettle and the water? The thermal capacity of the kettle is $4 \times 0.21 = 0.84$ B.t.u. The 4-lb. kettle has the same thermal capacity as 0.84 lb. of water. Its water equivalent is 0.84. We may then treat the problem the same as if we had had 8.84 lb. of water and no kettle. Hence, $8.84 \times (212 - 62) =$ 1,326 B.t.u., the amount of heat given to kettle and water.

Study Questions

1. If the body liquids had the same specific heat as mercury, what effect would we experience in a sudden change in the temperature of the air?
2. What are the relative specific heats of milk, tea, coffee, cocoa?
3. Why is a tin cup more unsatisfactory as a coffee cup than one of china?
4. Will a moist or a dry rice pudding cool the quicker? Why?
5. If the density of water is taken as 1 and that of air as 0.0010, how much air must pass through the floor register, its temperature change being 200° F., compared with the amount of water in a radiator with a temperature change of 20° F., in order to give the same amount of heat to a room?
6. It has been noticed that an aluminum tea kettle takes longer to boil the water than a tin kettle. Explain.
7. Compare grandmother's bag of hot salt with the modern hot-water bag as a supplier of heat.

8. The heat capacity of water is five times that of soapstone. Then why use soapstone in the fireless cooker?

9. Will the heat capacity of a juicy or a dry berry pie be the greater? Why?

10. A bath tub had 5 gal. of water at 90° C. added to 12 gal. of water at 14° C. What was the final temperature, assuming that the water equivalent of the tub is 3 gal. of water? *Ans.* 33° C. or 44.4° C.

11. To 200 g. of coffee at 45° C. add 15 g. of cream at 15° C. What is the resulting temperature, neglecting the effect of the cup? Specific heat of the coffee assumed to be 0.98. *Ans.* 43.5° C.

12. A 4-lb. flatiron at 212° F. placed in 5 lb. of water at 55° F. warms the water to 67° F. What is the specific heat of iron?

13. A carriage foot warmer made of brick weighs 6 lb., its temperature is 300° F. On its cooling to 60° F., how much heat is given out?

14. Will 1,000 cal. of heat always produce the same effect in cooking a given article? Why?

15. From the standpoint of the rapid cooking of potatoes, is there any advantage in a temperature of 250° F. as compared with a temperature of 212° F.? Why?

16. Find the specific heat of an aluminum dish from the following data: Mass of dish 1.5 lb., temperature of the dish 65° F., mass of hot water poured into the dish 2 lb., temperature of hot water 200° F., temperature of dish and water 181.6° F.

17. If 500 g. of iron were raised from 20 to 600° C., red heat, and 500 g. of water were raised from 20 to 100° C., which would have the more heat?

18. If the bodily temperature of a 120-lb. person is raised from 98.6 to 101.6° F., how much heat was required?

19. An aluminum spider of mass 2.5 lb. and an iron spider of 3.75 lb. both receive the same amount of heat. What will be their relative temperatures?

20. A 10-lb. soapstone heated to 400° F. is used in a fireless cooker in place of a can with 10 lb. of water at 212° F. Both cooled to 100° F. Which gave out the more heat?

Some Suggested Laboratory Exercises

1. Determination of the water equivalent of a vessel.
2. Specific heats of aluminum, granite ware and tin.
3. Specific heats of a liquid, as cocoa.
4. Heat capacity of a flatiron, a soapstone radiator under fixed conditions.

REVIEW SUMMARY

Heat is a quantity, temperature a condition. No fixed relation between the amount of heat and the temperature of different bodies.

Calorie = the amount of heat required to raise 1 g. of water 1° C. British thermal unit = the amount of heat required to raise 1 lb. of water 1° F.

One B.t.u. equals 252 cal.

Thermal capacity of a body is the amount of heat required to change its temperature 1°.

Thermal capacity of a substance is the amount of heat required to change unit mass 1°.

Specific heat is the ratio of the amount of heat required to change a given mass of the substance 1° to the amount of heat required to change the same mass of water 1°.

Specific heat and thermal capacity of a substance are numerically equal.

CHAPTER XIII

HEAT ENERGY FROM FUELS

127. Fuels.—A fuel may be defined as any substance which, on being oxidized or burned, produces heat energy in commercial quantities. The important element in all fuels is carbon, pure, or in compounds formed by union with hydrogen, nitrogen, oxygen, etc. Solid fuels contain moisture and ash. Liquid fuels usually contain impurities mixed with the carbon compounds. In gaseous fuels, uncombined gases like hydrogen, oxygen, etc., may be present together with the carbon compounds.

The heat relations associated with the oxidation of chemical elements and compounds have been determined by careful experiments, and, as a result, one can compute the fuel value of liquids, gases, and approximately of coals, when a complete chemical analysis is given. But as this entire topic really belongs in the field of chemistry, only a description of one of the many types of calorimeters used in fuel determinations and a table of heat values for some of the fuels commonly used in the home, will be given here.

The heat of combustion or fuel value of a substance is the heat produced when unit mass or volume of the substance is oxidized or burned.

128. Parr Calorimeter.—Figure 74 shows the assembled calorimeter with motor for stirring. Figure 75 shows the various parts in their relative positions, while Fig. 76 gives a more detailed view of the bomb and its electric ignition. A weighed sample of the substance whose fuel value is to be found is put into the bomb and thoroughly mixed with a measured amount of sodium peroxide ($Na_2 O$). The oxygen for the combustion is thus furnished by the $Na_2 O$. To insure a complete combustion of the sample, a known amount of

potassium perchlorate ($KCLO_3$) is added. This increases or intensifies the oxidizing effect of the Na_2O. The bomb, after sealing by the lock nut, is put into the calorimeter vessel A, and rests on the pivot F. A is filled with two liters of water.

Fig. 74.—Electric ignition calorimeter with electric motor and support.

The combustion is started by passing an electric current through the wire G, heating it to the fusion point. The heat from the combustion is imparted to the water and the rise of temperature noted on the accurate thermometer T.

The resulting rise of temperature is due to a number of factors. The fusion of the ignition wire produces a rise of

temperature of 0.003° C., and the combustion of the perchlorate a rise of 0.150° C. In the reaction that follows the ignition, 73 per cent very approximately of the heat is due to the combustion of the fuel and 27 per cent is due to the heat combination of CO_2 and H_2O with the chemicals. The heat capacity

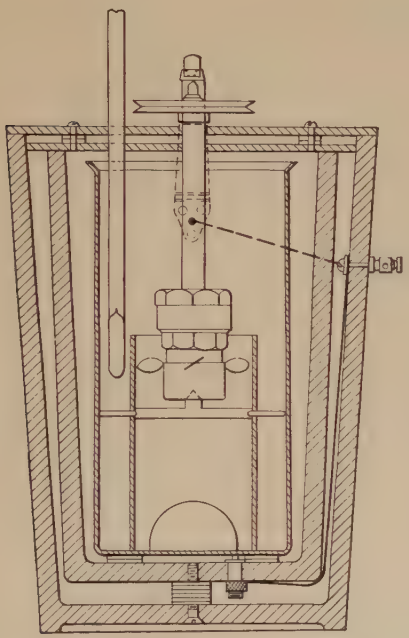


Fig. 75.—Sectional view of calorimeter.

Fig. 76.—Sectional view of bomb and electric ignition.

of the water and the metal, including the calorimeter, is equivalent to 2,123.3 g. of water. The empirical formula for computing the heat value of the fuel is

$$\text{B.t.u. per pound} = \frac{t \times 0.73 \times 2{,}123.3}{\text{weight of fuel in grams}}.$$

The following data from a laboratory exercise will make clear the method of computations:

Temperature of calorimeter and contents	19.70 C.
Temperature of calorimeter and contents after ignition	21.471 C.
Rise of temperature	1.771 C.
Rise of temperature corrected for fuse wire (0.003), Chlorate (0.150) and special chemical (0.371)	1.247 C.
Rise of temperature due to combustion of the alcohol 1.247×0.73	0.91 C.
Heat gained by calorimeter and contents due to combustion of alcohol $2,123.3 \times 0.91$	1,932.2 cal.
Weight of fuel used	0.3 g.
Heat produced from 1 g. of fuel	6,440.6 cal.
Heat produced in B.t.u. by 1 lb. of alcohol. $\frac{6,440.6 \times 453.6}{252}$	11,600

Using the empirical formula, with the temperatures expressed in degrees Fahrenheit and the weight of the substance in grams:

$$\frac{(3.118 - 0.943)0.73 \times 2,123.3}{0.3} = 11,600 \text{ B.t.u. per pound.}$$

129. Some Heats of Combustion.

	British Thermal Units per Pound Average Values
Anthracite—hard coal	14,000
Bituminous—soft coal	14,500
Coke	7,000
Charcoal	16,000
Soft wood—air dry, 4,000 lb. per cord	8,000
Hard wood—air dry, 6,000 lb. per cord	8,000
Kerosene, 6.5 lb. per gallon	20,000
Gasoline, 5.5 lb. per gallon	21,000
Alcohol, 90 per cent denatured, 6.8 lb. per gallon	11,600
	British Thermal Units per Cubic Foot
Natural gas	1,000
Coal gas	700
Water gas	320
Producer gas	140
Manufactured gas, usual city gas	450–600
Electricity per kilowatt-hour	3,412 B.t.u.

	Kilo-calories per Gram
Dry protein	5.35
Fat	9.45
Carbohydrate	4.1
Roast beef	3.57
Roast chicken	1.81
Roast pork	2.10
Roast mutton	3.13
Salmon	1.98
Butter	7.95
Olive oil	9.30
Cheese, American	4.53
Cabbage	0.05
Potatoes, white baked	1.14
Apples, fresh	0.49
Bread, baker's white	2.68
Oatmeal	0.63
Corn flakes	3.67
Sugar	4.10
Honey	3.35

130. Comparison of Fuels.—In the comparisons made below it should be noticed that any advantage or disadvantage the type of stove or burner may offer is neglected, as well as the factors of convenience and cleanliness.

	British thermal units for one dollar	Relative amount in terms of smallest
Soft coal at $5 per ton	5,800,000	170
Hard coal at $7.50 per ton	3,732,400	109
Fuel oil at $2 per barrel	3,700,000	108
Coke at $5 per ton	2,800,000	82
Soft wood at $4 per cord	8,000,000	234
Hard wood at $5 per cord	7,600,000	222
Kerosene at $0.15 per gallon	860,000	25.2
Gasoline at $0.20 per gallon	577,500	17
Alcohol at $0.60 per gallon	130,964	4
Manufactured gas at $1 per 1,000 cubic feet	600,000	17.5
Electricity at $0.10 per kilowatt-hour	34,120	1

The table gives the amount of heat in B.t.u. that can be purchased for $1 at the prices stated and also in the last column the relative amount of heat obtained for $1 in terms of the smallest amount.

Illustrative Problems

1. Assuming that a given home requires 40,000 B.t.u. per hour to heat it, find the number of pounds of soft coal that must be burned in a hot-air furnace when only one-half of the heat produced is usable.

1 lb. of soft coal gives 14,500 B.t.u.
40,000 ÷ 14,500 = 2.75 lb. of coal if all the heat went into the house. 2 × 2.75 = 5.5 lb. actually required.

2. A gas plate delivers about 18 cu. ft. of gas per hour, while a gas oven may require 40 cu. ft. per hour. If the gas plate is 50 per cent efficient and the oven 15 per cent how much useful heat was furnished?

1 cu. ft. of gas has, say, 500 B.t.u.
18 × 50 per cent = 9 cu. ft. used. 9 × 500 = 4,500 B.t.u.
40 × 15 per cent = 6 cu. ft. used. 6 × 500 = 3,000 B.t.u.

3. What is the cost of heating 8 lb. (4 qt.) of water from 62 to 212° F. on the plate in Problem 2 when gas is $1.50 per 1,000 cu. ft.? What is the cost if electric heat is used, 85 per cent efficiency and electricity is 10 cts. a kilowatt hour?

8 × (212 − 62) = 1,200 B.t.u. required.
1,200 ÷ 0.5 = B.t.u. given by the gas = 2,400.
2,400 ÷ 500 = cu. ft. of gas consumed = 4.8 cu. ft.
Cost of gas per cubic foot is 0.150 cts.
4.8 × 0.15 = 0.72 cts.
1,200 ÷ 0.85 = B.t.u. necessary = 1,411 B.t.u.
1 kw.-hr. furnishes 3,412 B.t.u.
1,411 ÷ 3,412 = kw.-hr. to be furnished = 0.41 kw.-hr.
0.41 × 10 cts. = 4.1 cts.

Study Exercises

1. If 3 lb. of olive oil were heated from 60 to 300° F. by the consumption of 0.96 cu. ft. of gas, what was the efficiency of the burner?

2. A kerosene vapor burner, 55 per cent efficiency, consumed $\frac{1}{10}$ lb. of oil. What temperature rise was produced in 8 lb. of water?

3. Assuming an efficiency for a given gas burner of 45 per cent and for an electric hot plate of 60 per cent, find the cost of electricity per kilowatt hour to compete with gas at $1 per 1,000 cu. ft.

4. If the burning of 1 cu. ft. of gas will produce 600 B.t.u., how many calories will be produced? How many degrees will the temperature of 2.5 lb. of water be raised, assuming one-half the heat goes into the water?

5. If a kerosene burner is 35 per cent efficient, oil costing 20 cts. per gallon, and an alcohol burner has the same efficiency, alcohol costing 75 cts. per gallon, which is the cheaper fuel to use?

6. In the Parr calorimeter the following data were obtained for the combustion of peanut butter: Temperature of water at start 19.5° C., temperature at the end 20.38° C., mass of peanut butter 0.3 g., mass of water 2,000 g. and water equivalent of calorimeter 123.3 g. Find fuel value.

7. One pound of a Washington coal has 10,000 B.t.u. If a cook stove transmits but one-half of 1 per cent of the heat in the coal to a vessel on the stove, what would be the rise in temperature of 1 pt. of water? Neglect all losses.

8. One kilowatt-hour of electricity is furnished to 4 qt. (8 lb.) of water. Assume 90 per cent of the heat goes into the water. What is the cost of heating the water from 62 to 212° F. at 2 cts. a kilowatt-hour.?

9. A certain room requires 16,000 B.t.u. per hour to keep it at 68° F. A hot air furnace may be assumed to send 40 per cent of the heat from the coal into the room. How many pounds of coal, 10,000 B.t.u. per pound, must be burned?

10. From the laboratory data on efficiency of various types of stoves, find the relative cost to boil 8 lb. of water.

Some Suggested Laboratory Exercises

1. Heat of a fuel—Parr calorimeter.
2. Heat of combustion of gas.
3. Working efficiency or ratio of the heat gained by a kettle of water to the heat given out by various fuels in different types of stoves: gas, gasoline, kerosene, alcohol, electric. Stove or burner efficiency.
4. Study of the differences in efficiency of various teakettles on one type of stove: tin, nickel (copper bottom), granite, aluminum, cast and spun kettles.

REVIEW SUMMARY

Fuel defined as any substance which on being burned, produces heat in commercial quantities.

Heat of combustion is the amount of heat produced when unit mass or volume of a substance is burned.

Description of the Parr calorimeter.

Comparison of fuel costs.

CHAPTER XIV

MECHANICAL EQUIVALENT OF HEAT

131. Theories of Heat.—Up to nearly the first half of the nineteenth century, scientific men were inclined to believe that heat consisted of an elastic fluid which they called *caloric*. On this general hypothesis they explained the flow of heat from hot to cold bodies which are in contact by saying that caloric was a self-repellant substance, it was repelled from the hot body where it was in abundance to the cold body where it was lacking. The difference in specific heats of different substances found an easy explanation by assuming that matter attracted caloric, the amount of attraction depending upon the chemical constitution of the body. Caloric was considered to be indestructible and also uncreatable. They said the constant temperature of melting ice or boiling water, while caloric was being continually added, was due to the caloric getting between the molecules of the substance, being thus hidden in its effects. We still have the old idea suggested in the use of the terms *latent heat of fusion* and *latent heat of vaporization*.

Rumford, an American, working in Munich, was one of the first to think of heat as due to motion. He caused a cannon to be bored out by the work of horses turning the borer. He calculated that the heat produced in this way by friction was equal to that produced by the combustion of nine wax candles. To Rumford, because of the fact that from his experiment there appeared to be no limit to the amount of heat produced by friction, the idea of a heat substance, caloric, did not seem reasonable.

Davy, in 1799, published an account of his work in melting ice by rubbing two pieces together. Everyone agreed that a rather large amount of heat must be given to a mass of ice at 0° C. in order that it might be melted into water at the same

temperature. The explanation of the calorists that this amount of heat was squeezed out of the ice or came from the heat capacity of water being less than that of ice, was not readily accepted. Davy showed also, as had Rumford, that the amount of ice melted depended on the amount of rubbing or friction, hence the amount of heat was unlimited. The idea of the *material* nature of heat was slowly being abandoned.

132. Work and Heat.—The experiments of Rumford and Davy both depended upon work being done and it was natural to raise the question of there being a relation between heat and work. What is the relation between the work done and the heat produced? Joule of Manchester gave the first satisfactory answer about 1840.

But in 1842, Mayer, a physician, had stated his belief in an equivalence between the work done and the heat produced. Helmholtz, the physician and physicist, had independently stated the same belief. These statements, when generalized, become the principle of the conservation of energy. Preston in his "Theory of Heat" gives the meaning of the principle in these words:

> According to the law of conservation the universe is endowed with a store of energy which, through all the varied changes of natural processes, can neither be increased or diminished, but which, though passing through ever varying phases of transformation, is, like the matter of the universe, unchanging in quantity from eternity to eternity, all changes and phenomena are due simply to variation in its mode of appearance. Here we find one portion of it as the *vis viva* (energy) of masses in motion as a whole, or as the vibrations of their parts, and there we detect another in the ethereal waves which produce light and radiant heat; while, on the other hand, we locate vast quantities of it in the energy of position of huge masses, or of their constituent molecules under the names of potential and chemical energies. This probably is engaged in the process by which one body attracts another and one molecule another, while in perhaps some similar way a portion is distributed in the ether around magnets, or engaged in electrical processes.

133. Joule's Work.—While the principle of the conservation of energy as announced by Mayer and others was more or

less accepted, it remained for Joule to show its truth in the field where it seemed most doubtful, the production of heat from work and work from heat.

A quantity of water was placed in a vessel AB which was fitted with a paddle system and with means for determining the temperature of the water. The paddles were rotated by the falling weights *ee*. The work done by the paddles on the water is equal to the product of the weights times the distance fallen. This work resulted in a rise of temperature in the vessel AB. This is, in brief outline, the famous experiment

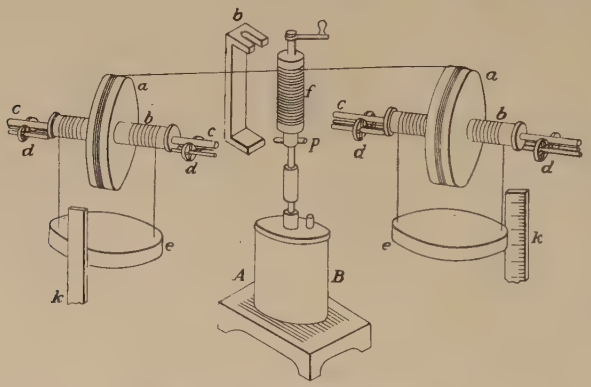


FIG. 77.—Joule's apparatus.

of Joule, from which he was able to find the relation between work and heat. This relation is expressed by the equation

$$\text{Work} = J \times \text{heat or } J = \frac{W}{H}.$$

To the factor J, the name "mechanical equivalent of heat" has been given.

To produce 1 cal. of heat, 427 g.-m. of work must be performed, and in the English units, 778 ft.-lb. of work will produce 1 B.t.u. The following are some of the more commonly used values for J:

J = 427 g.-m. per calorie = 427 kg.-m. per kilo-calorie = 778 ft.-lb. per B.t.u.

3,088 ft.-lb. = 1 kilo-calorie.

The result, then, of Joule's work was to establish the fact that heat is a form of energy, and the question arises at once as to the nature of the energy represented by heat. We have abundant evidence that the molecules of a substance are not at rest but are in continual motion and so these molecules must possess kinetic energy. The addition of heat energy to a body, if its temperature rises, increases the velocity of the moving molecules and so increases their kinetic energy. *Heat energy, then, is due to the motions of the molecules of a body and as these molecular motions are increased or decreased, so is the amount of heat energy.*

Illustrative Problems

1. In a certain baking operation in a gas oven, 60 cu. ft. of gas were consumed. If the heat energy of the gas had all been converted into work, how much work could have been done?

$$60 \times 500 = 30{,}000 \text{ B.t.u. in the gas.}$$

$$W = JH, \text{ so } W = 778 \times 30{,}000 = 23{,}340{,}000 \text{ ft.-lb.}$$

2. In raising 1 qt. (2 lb.) of water from 62 to 212° F., 300 B.t.u. are required. The heat energy if converted into work would have performed $300 \times 778 = 233{,}400$ ft.-lb.

3. The gas having been found to be turned off, the cook decided to boil the water for the breakfast coffee by shaking it in a long tube. She used one pint (1 lb.) of water at 62° F. and the water fell 2 ft. at each shake. She made 30 shakes per minute. Neglecting any loss of heat, how long did it take her boil to the water?

Since 150 B.t.u. were required, the work to be done was $150 \times 778 = 116{,}700$ ft.-lb. Each minute the cook did $30 \times 2 \times 1$ ft.-lb., or 3,600 ft.-lb. per hour. The time required was therefore $116{,}700/3{,}600 = 32.4$ hr.

4. For breakfast a person ate one slice of toast whose fuel value is 62 kilo-calories, one shredded wheat biscuit, 109 kilo-calories, cream, 108 kilo-calories, sugar 1 teaspoonful, 49 kilo-calories, and 1 orange, 96 kilo-calories. How much energy in foot-pounds was furnished?

Total fuel value $= 62 + 109 + 108 + 49 + 96 = 424$ kilo-calories.

One kilo-calorie = 3,088 ft.-lb.

So the energy furnished was 1,309,312 ft.-lb.

If we assume that one-fifth of this energy could be converted into work by the person and that she could work at the rate of 0.05 hp., how long could she work on the energy furnished by the breakfast?

One-fifth of 1,309,312 = 261,862 ft.-lb. available for working.

Each minute the work done was $33{,}000 \times 0.05 = 1{,}650$ ft.-lb.

Hence,

$$\frac{261{,}862}{1{,}650} = 158.7 \text{ min.}$$

Study Exercises

1. If 1 lb. of water is heated from 60 to 212° F. by the method of Joule, how much work is performed?

2. One pound of coal has 10,000 B.t.u. If all this heat could be converted directly without loss into work for running a sewing machine, which is assumed to require 1650-ft.-lb. per minute to operate, how long could the machine be run?

3. If we assume that a man can do 198,000 ft.-lb. per hour, how much heat energy would be required to do the same amount of work?

4. A liter of water (1,000 g.) is placed in a tube 1 m. long, closed at both ends. By inverting the tube the water falls through 1 m. and 1 k.-m. of work is performed on it. How much work must be done to raise the temperature of the water from 20 to 100° C.? Neglect any loss of heat. If the tube can be inverted forty times a minute, how long will it take to boil the water?

5. The fuel value of 1 gal. of gasoline is 115,500 B.t.u. Using the data of Problem 30 (p. 48) find how far the automobile should travel if all the heat energy was transformed into work. In actual practice, 16 miles per gallon is, perhaps, a fair average for an automobile.

6. If Multnomah Falls are 1,200 ft. high, how much warmer should the water be at the bottom than at the top?

7. If all the heat energy in 40 cu. ft. of gas of 500 B.t.u. per cubic foot, the amount used in a gas oven in one hour, could be converted into electrical energy, how long could an incandescent electric lamp, using $\frac{1}{10}$ kw., be burned?

134. Heat Engines.—The conversion of heat into work by various forms of heat engines, steam, gasoline, crude oil, hot air, etc., has helped greatly the progress of the human race. The work done in the earlier times by human beings or by animals is now performed to a great extent by heat engines, and the race, freed from some of the heavy drudgery, has had its energy saved for higher forms of work. The home is one of the last great fields where human energy is used almost to the exclusion of the modern machines for lessening human drudgery.

135. Cost of Work.—An efficient steam engine will use about 2 lb. of coal for 1 hp.-hr. (33,000 × 60 ft.-lb.) and at $3 a ton for coal the cost of this amount of work is 0.3 cts. A gasoline engine using 0.1 gal. of gasoline costing 15 cts. a gal., will produce the same amount of work for 1.5 cts. A team of horses and man at $10 per day will perform the same amount of

work at a cost of 50 cts. A man, working hard at the rate of 0.1 hp., will cost at $4 per day when he has performed a hp. hour of work, $5.

A woman will take, say, 3 hr., to do the laundry work that the washing machine will do in 30 min. If the woman received 50 cts. per hour, the cost of her work is $1.50. A 0.1-hp. electric motor with electrical energy at 10 cts. a kilowatt-hour will cost to run about 0.3 ct. and the time of the woman 12.5 cts. Thus the total cost for that part of the washing done by the machine will be 12.83 cts. A lecturer on India said that "coolie" labor was still used there very largely because a pound of rice burned in the "coolie" was a cheaper fuel than a pound of coal burned in a boiler.

136. The Human Body, a Machine.—Can the human body be considered as a machine in its energy transformations? The following interesting extract from a paper, written by Joule, in 1846, gives his view on the question:

> A horse, when its power is advantageously applied, is able to raise a weight of 24,000,000 lb. to a height of 1 ft. per day. In the same time (24 hr.) he will consume 12 lb. of hay and 12 lb. of corn. He is able, therefore, to raise 143 lb. by the consumption of 1 grain of mixed food. From our own experiments on the combustion of a mixture of hay and corn in oxygen gas, we find each grain of food consisting of equal parts of undried hay and corn, is able to give 0.682° to 1 lb. of water, a quantity of heat equivalent to the raising of a weight of 557 lb. to a height of 1 ft. Whence it appears that one-fourth of the whole amount of *vis viva* (energy) generated by the combustion of food in the animal frame is capable of being applied in producing a useful mechanical effect—the remaining three-fourths being required in order to keep up the animal heat, etc. If these theoretical views be correct, they would lead to the interesting conclusion that the animal frame, though destined to fulfill so many other ends, is, as an engine, more perfect in the economy of *vis viva* than the best of human contrivances.

The views of Joule on the body as a machine were those generally held, but whether the principle of the conservation of energy could be applied to the body was not so certain. Not until 1893 was the validity of the assumption experi-

mentally confirmed, and at the present time, due largely to the careful experiments of Atwater at Wesleyan University, the question may be considered as definitely settled.

With the establishment of the fact that the human body may be treated as a machine, and that the principle of the conservation of energy also holds, the two questions of the efficiency of the body as a transferer of energy and the mechanical output of a man's body during a day of work came to be considered.

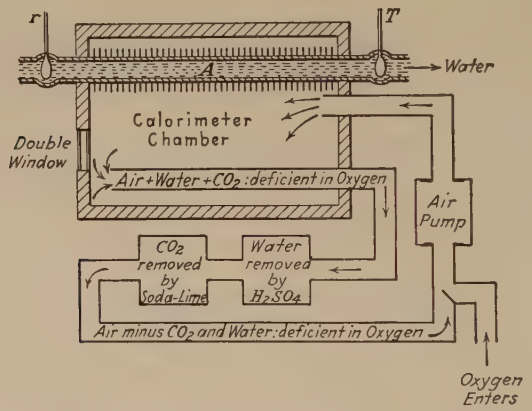


Fig. 78.—General view of Atwater-Benedict respiration calorimeter.

It is rather astonishing to find that men are capable of very great muscular exertion for short periods. The rate of work done by engines and various machines is computed in horse-power units, where 1 hp. is assumed to be 33,000 ft.-lb. of work per minute, or 4,562.4 kg.-m. per minute. The table given below is one reported by Blix, modified by adding a column expressing the rate at which the work was done in horse-power units.

Benedict and Cathcart report, from one of their experiments, the work done by one man to have been at the rate of 0.19 hp. for a continuous period of 4.5 hours. This, they think, is the greatest sustained muscular work so far reported. It is usually assumed that a man working hard for a day can

work at the rate of $\frac{1}{10}$ hp., or in heat energy units 1.07 k.-cal. per minute.

Kind of work	Length of work period	Work done per minute by the man, kilogram meters	Horse-power	Calories
Mountain climbing, moderate	Many hours	500	0.11	1,160
Mountain climbing, severe	1 to 2 hr.	750–1,000	0.16–0.22	1,740–2,330
Climbing a treadmill	30 sec.	2,400–3,600	0.52–0.78	5,580–8,370
Running upstairs, 22-lb. load	15 sec.	3,700	0.80	8,610
Running upstairs, no load	30 sec.	4,300	0.95	10,000
Running upstairs, no load	4 sec.	6,000	1.32	13,950

137. Expenditure of Energy.—The table[1] below gives the approximate average hourly energy expenditure by an average-sized man, without clothing, under different conditions of activity. The table has been modified by some omissions and by the addition of the last column. While Sherman has computed the data for a man without clothing, he says he has so treated the factors of food and clothing that the data is usable for practical purposes for the clothed body:

Condition or occupation	Number of calories (kilo) required	Energy required in foot-pounds
Sleeping	60–70	200,720
Awake, lying still	70–85	237,776
Sitting at rest	100	308,800
Standing at rest	115	355,120
Typewriting rapidly	140	447,760
Light exercise	170	524,960
Walking (about $2\frac{2}{3}$ miles per hour)	200	617,600
Severe exercise	450	1,389,600

[1] SHERMAN: *Proc. Inst. Med.*, Vol. 2. 1918.

For the average man or woman the total energy requirement for a day of 24 hours can be computed by multiplying the hour rate of energy expenditure by the number of hours spent in each different condition or activity, adding the products and increasing or decreasing the total in proportion as the body weight is above or below 154 lb.

For example, assume a woman of weight 120 lb.:

	Hours	Energy Requirement Kilo-calories
Sleeping	8	520
Sitting at rest	2	200
Typing	3	420
Light exercise	6	1,020
Walking	1	200
Severe exercise	4	1,800
Total		4,160

$4{,}160 \times 120/154 = 3{,}241$ kilo-calories for the woman.

Illustrative Problem

1. During an evening a 120-lb. young woman ate ¼ lb. of candy. Candy has a food value of 1,785 kilo-calories per pound. How far could she have walked on the level on the energy furnished by the candy, assuming an efficiency of 20 per cent?

$1{,}785 \div 4 = 446$ kilo-calories in the candy.

20 per cent of 446 = 89 kilo-calories available for walking.

A 120-lb. person walking 1 ft. on the level expends $0.0672 \times 120 = 8.06$ cal. or 0.00806 kilo-calories (Art. 138).

$89 \div 0.0{,}086 = 10{,}348.8$, the distance in feet to be walked, or 2 miles approximately.

138. Energy Required for Walking and Studying. (*a*) *Walking.*—To express the work done in walking along a horizontal plane, it is convenient to use as the unit of work, the horizontal foot-pound, that is, the work done when a 1-lb. mass is moved forward horizontally 1 ft. This has been found by careful experiments to increase the heat output of the body by 0.0672 cal. If, then, a 120-lb. housewife walks, during a forenoon's work in the home, a distance of 2 miles, she has performed $120 \times 5{,}280 \times 2$ horizontal foot-pounds of

work with an increased heat output from the body of 120 × 5,280 × 2 × 0.0672 = 85,157 cal. = 85.157 kilo-calories. Since 1 kilo-calorie = 3,088 ft.-lb., the amount of work done by walking expressed in mechanical units was 262,943 ft.-lb. If this work was done in 4 hours, she was working, while walking, at the rate of 0.03 hp.

(*b*) *Studying.*—Numerous experiments have been made in an attempt to measure mental work in the same way that bodily work has been measured. A rather extended series of experiments were made by Benedict and Carpenter on 22 college students doing the mental work incident to 3-hour written semester examinations. The conclusion reached by them is stated in part as follows:

> From the results of the data accumulated in this series of experiments on the effect of mental work on metabolism it would appear that the pulse rate was slightly increased, the body temperature somewhat higher, the water vapor output increased by about 5 per cent, the carbon dioxide production increased by about 2 per cent, the oxygen consumption increased by about 6 per cent, and the heat production increased by about ½ per cent. On the whole, however, the increase of heat production and carbon dioxide elimination accompanying the mental exertion is so small and the exceptions so numerous that it would not be wise to say whether or not the mental activity exercised a positive influence on metabolic processes in general.

139. Body Efficiency.—The efficiency of a machine is usually defined as the ratio of the work done *by* the machine to the work done *on* the machine. It will be noticed in the quotation from Joule, a result of 25 per cent efficiency was obtained in just this way. More frequently, perhaps, what is called the gross efficiency, crude efficiency, or industrial efficiency is obtained by taking the energy of the effective muscular work expressed in heat units and dividing it by the *total* energy output of the man. Different machines differ in their efficiency and also the same machine will have different efficiencies for varying loads and speeds. Man, as a machine, seems to act in the same way. We may take 20 per cent as the approximate efficiency of the human machine under

ordinary conditions. The curves given below, taken from Carnegie Institute Bulletin 187, show these facts strikingly.

The facts and relationships considered in this chapter furnish the basis for many of the questions raised in the study of foods and nutrition, in the size and kind of "portion," and indeed in the whole matter of standardization of diet.

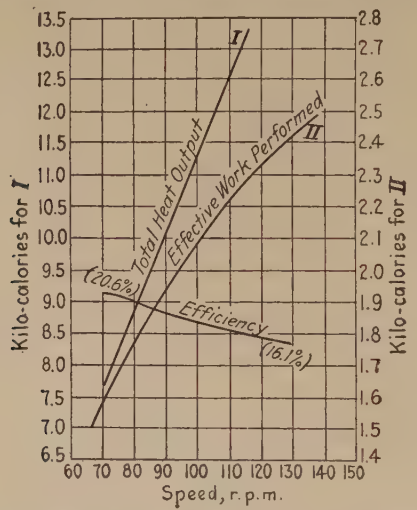


FIG. 79.—Curves showing total heat output per minute, expressed in kilo-calories for a rider under constant load, at varying speeds. Also efficiency curve added by the writers. The speed in revolutions per minute is given at the bottom of the figure, the heat output at the left, the effective work expressed in calories at the right. The third curve shows the ratio of effective work to total heat output or gross efficiency at different speeds. The numbers in brackets represent the efficiencies in per cent.

Study Exercises

1. When, how and where is heat developed as the equivalent of the work done when a man (*a*) jumps down on soft ground, (*b*) slides slowly down a rope, (*c*) walks downstairs?

2. If 4-qt. of water, 8 lb., are heated from 60 to 212° F. by shaking, how much work was done?

3. A gas oven required 40 cu. ft. of gas to do a baking. How much energy in foot-pounds was consumed?

4. If 3,000 kilo-calories of food energy are consumed by a man whose efficiency is 21 per cent how much work can he do? If he worked 8 hours, what was his rate of doing work?

5. If a certain standard diet consists of protein, 75 g.; fat, 40 g.; carbohydrates, 400 g., how many kilo-calories will be available for muscular work, assuming that 25 per cent of the heat energy input can be transformed into work?

6. What is the efficiency of a man whose work output in kilo-calories was 1.37 and whose total heat output was 6.7 kilo-calories?

7. After violent exercise one feels hot. Is the body at a higher temperature than normal? Explain.

8. By the friction of wood on wood, primitive peoples were able to start a fire. Explain what Joule added to this general fact.

9. Assume a student will work during the day at the rate of $\frac{1}{40}$ hp. and that she is 20 per cent efficient as a machine. Prepare a day's menu for the student giving a balanced diet and the amount of grams of each article of food.

Some Suggested Laboratory Exercises

1. Mechanical equivalent of heat. Method of tube and falling shot.
2. Mechanical equivalent. Callendar's apparatus.
3. Rough determination of the work performed in boiling 50 g. of water.

REVIEW SUMMARY

Early theory of heat assumed it to be a substance, caloric.

Rumford and Davy from their experiments believed heat to be due to molecular motion.

Joule first showed that the heat appearing and the work performed have a fixed relationship.

The mechanical equivalent of heat is the number of work units equal to one heat unit.

One B.t.u. = 778 ft.-lb. 1 cal. = 427 g.-m.

Heat engines are devices for transforming heat energy into mechanical energy.

Human body may be considered as a boiler for the burning of food fuel. As a machine the human body is about 20 per cent efficient.

Table of energy expenditure by the body under different conditions.

Energy required in walking, about 0.0672 cal. per horizontal foot pound.

CHAPTER XV

CHANGE OF STATE

140. Fusion and Solidification.—We must consider the molecules of a solid as having definite positions with respect to each other and that these fixed positions are the result of molecular forces that act between the molecules. When heat is applied to a solid the velocity and hence the kinetic energy of the molecules increases, until, for each substance, the temperature reaches a definite value, where it remains stationary. If more heat is supplied, the attractions between the molecules are broken up and the molecules are no longer compelled to maintain their fixed positions, but can wander among the other molecules. The solid begins to liquefy or melt. This separation of the molecules makes necessary the performance of work, hence the passage from the solid state requires the consumption of energy which is supplied by the added heat. The heat energy, then, during fusion or melting, goes not to increasing the temperature but to doing internal work on the molecules. This gives them a potential energy which they did not have before. In the liquid state the kinetic energy of the molecules and the decrease in the molecular forces are sufficient to prevent any permanent union between the molecules. As the temperature of the liquid falls, there is a decrease in the strength of the molecular impacts and the molecular forces now draw the molecules together into permanent positions, and the liquid becomes a solid. The work which the molecular forces do in moving the molecules nearer together appears as kinetic energy, equal in amount to the potential energy possessed by the molecules in the liquid state. This kinetic energy appears as heat. *Change of state, then, always involves an absorption or liberation of energy.*

141. Fusion or Melting Point.—When the temperature of a solid is gradually raised there is a temperature at which the solid changes into the liquid. This temperature is called the fusion or melting point of the substance.

In crystalline substances, as ice, for example, there is a definite temperature at which the solid melts with no further increase in temperature, until it is all in the liquid state.

In the non-crystalline substances, as fats, jellies, glass, wax, paraffin, etc., there is no definite point, sharply defined, at which the substance melts. But as the temperature rises the substance becomes more plastic, gradually reaching a semi-solid viscous condition where it partakes of the properties of a solid and a liquid. It is in this state that glass can be easily bent, moulded, or drawn out, also wax and taffy candy are then easily worked. Lard begins to melt at about 32° C. (58° F.) and is melted to what is called the "clear drop" at about 46° C. (83° F.); butter melts usually between 28 and 33° C.; fresh beef tallow melts near 43° C.

142. Change of Volume.—Substances, in general, contract when they solidify and expand when they melt. Ice, iron and type metal are among the exceptions, and it is because of this that iron can be molded, since on solidifying, it expands and fills all parts of the mold. If 917 cc. of water are frozen, the volume of the ice will be 1,000 cc. or the volume has increased 9.3 per cent. When water enclosed in a pipe freezes, it exerts an enormous pressure in changing from the liquid to the solid state. This pressure is comparable with the pressures produced by expanding water due to rise of temperature discussed in a previous chapter.

143. Effect of Pressure on the Melting Point.—When walking on the sidewalk after a light fall of snow, with the temperature below freezing, nearly everyone has had "ice balls" form on the heels of her shoes. One may, too, frequently follow the track of ice left behind the wheels of a loaded wagon as it passes down the snow-covered street. We may look upon the melting of ice as a process of contraction, neglecting the heat side, and when we apply pressure we are helping the snow to contract, that is, liquefy, and so the

snow can melt at a lower temperature than 0° C. But when the pressure is removed, the water expands to the solid state since the surrounding temperature is then too low for it to remain a liquid. Since paraffin contracts on solidifying, increase of pressure on the solid paraffin would mean a melting at a higher temperature. We can see that if a substance expands on melting, increase of pressure will hinder the process and the melting point will be raised; but if the substance contracts on melting, the effect of increase in pressure is to *help* the process and the melting point will be lowered. In the one case *more*, and in the other case *less*, heat energy is required.

An interesting application of the pressure effect is found in skating. The skate blade is so curved and touches for so short a length, that the pressure is very great. It has been estimated that the bearing area is $\frac{1}{50}$ sq. in. and if the skater weighs 140 lb., the pressure is 7,000 lb. per square. inch. This pressure causes a thin film of water to be formed between the surface of the ice and the skate, so the skater is actually gliding on a film of water, thus giving a freedom of motion exceeding that between two oiled surfaces.

144. Alloys.—By using proper proportions of certain metals, it is possible to obtain mixtures or alloys whose melting points are much lower than the melting points of any of the constituents. The common solder, used in mending pans and lead pipes in the house plumbing, is an alloy of lead and tin which melts at 190° C., a temperature 138° C. below the melting point of the lead pipe. The automatic fire-sprinkler system used in stores and factories depends for its action on an alloy plug of low melting point which, melting very soon after a fire starts, opens the water-filled pipes. An interesting

SOME MELTING POINTS

	Degrees Centigrade		Degrees Centigrade
Mercury	− 38.8	Platinum	1,730
Paraffin	38 to 52	Tungsten	2,800
Alcohol	−130	Glass	400
Tin	232	Stearin	60
Aluminum	655	Copper	1,068

alloy, illustrating the low melting point of some alloys, is one composed of bismuth 7 parts, lead 4 parts, tin 2 parts, and cadmium 1 part. This alloy, which melts at 70° C., can be molded into a spoon that will melt when used to stir a cup of coffee.

145. Latent Heat of Fusion.—Our grandfathers knew and made use of the fact that a tub of water in the cellar would protect the vegetables from frost on a cold night. The water in freezing gives out heat to the cellar. We put ice in the refrigerator to absorb the heat from the food. Water would do the same thing, except that in absorbing the heat from the food its temperature would rise. The ice melts, taking the heat from the food, but with no temperature effect on the ice.

If 1 g. of ice at 0° C. is placed in 1 g. of water at 80° C., the result is 2 g. of water at 0° C. Since the water was cooled through 80° C., 80 calories of heat were given to the 1 g. of ice in melting it. Conversely, when 1 g. of water freezes, 80 cal. of heat are given out. In general, freezing or solidifying is a warming process, heat being given out, while melting or liquefying is a cooling process, heat being absorbed.

If the 80 cal. of heat which are given out when 1 g. of water freezes could be converted into work, 1 kg. would be raised 34.16 m., or the energy liberated would be nearly equal to the work done by a ½-hp. engine working for a second.

The latent heat of fusion is the amount of heat necessary to melt unit mass of the substance.

SOME LATENT HEATS OF FUSION

	Calories per Gram	B.t.u. per Pound
Ice	80	144
Beeswax	97.2	175
Mercury	62	111.6
Aluminum	107	192.6
Lead	5.4	9.72

The slowness with which water freezes or ice melts is due to the large amount of heat that must be liberated or absorbed. To this fact is due the more nearly uniform temperatures near

large bodies of water. Along the shores of Lake Michigan there is a great peach region. The rather delicate peach buds receive some protection in the winter from the freezing lake and more in the spring as the melting ice keeps the temperature from rising too rapidly, thus forcing the growth of the buds.

Study Exercises

1. To what is due the change in the volume of ice cream on freezing?
2. If the latent heat of fusion of ice were unity, what would be the effect of the warm sunshine of a winter's day on the snow-covered ground?
3. A refrigerator melts 15 lb. (6,810 g. approximately) of ice in 24 hr. How many B.t.u. and how many calories of heat can be taken from the food? Neglect the effect of the heat which comes in from the outside.
4. If 4 qt. of water at 60° F. are to be reduced to 45° F. by icing, how many pounds of ice will be required?
5. A cellar 30 by 15 by 8 ft. contains 227 lb. of air and a tub of water freezes and produces 6 lb. of ice. Neglecting any loss of heat from the cellar, what rise of temperature will be produced?
6. Ten pounds of ice are to be melted and the water warmed to 80° F. Find the number of cubic feet of gas necessary, assuming the burner is 50 per cent efficient. How many cubic feet of gas will be needed to raise the same mass of water from 32 to 80° F.?
7. In a certain refrigerator with no food in it, 25 lb. of ice were melted in 24 hr. How many B.t.u. per hour passed through the walls?
8. In which will a frost probably come the sooner, a valley with a large body of water in it or a valley with no water? Why?

146. Heat of Solution.—In most cases when a salt dissolves in water we have a cooling effect. We have already seen that when solids liquefy or liquids solidify, there is a change in the heat energy content. So, in dissolving, a substance must take up a certain amount of heat energy and if this is not supplied to the system then it must get it from its own store of heat energy, which makes necessary a cooling of the solution. A simple illustration is the cooling of the cup of coffee as the lump or lumps of sugar are dissolved. In the super-saturated solutions of the chemist, made by dissolving a salt in a minimum of water, or by melting certain salts, as sodium sulphate, thiosulphate, etc., in their own water of crystallization, we have a liberation of the latent heat of solution when the solution is

shaken or a crystal of the salt is added. In the liquefaction a large amount of heat is absorbed which reappears when solidification takes place. The principle has been made use of in the Thermor ware now on the market. Metal dishes, plates, meat platters and coffee pots are provided with double bottoms or walls and the space between the walls is filled with a salt. When the vessel is placed in boiling water for a few minutes the salt is melted, absorbing heat; as the liquid cools and returns to the solid state, this heat is given up to the vessel and its contents. In the case of a covered dish, food was kept warm for an hour after being placed in the dish.

147. Freezing Mixtures.—Many substances when mixed with ice will produce a low temperature. A few are given below

	Degrees Fahrenheit
1 part of potassium chloride to 3 parts of ice.....	12
1 part of ammonium chloride to 4 parts of ice.....	5
1 part of sodium nitrate to 2 parts of ice.....	0
1 part of sodium chloride (salt) to 3 parts of ice.....	− 6
1.5 parts of calcium chloride crystals to 1 part ice...	−58

The lowest temperature that can be produced by any mixture is the freezing point of the saturated solution of that mixture. The addition of an excess of the salt *hastens* the freezing, but does not produce a lower temperature. A deficiency of the salt slows up the freezing and the temperature fall is not so great. So, for quick freezing of ice cream, the proportions are not 1 part of common salt and 3 parts of ice, but a greater amount of salt.

The following explanation of the process of freezing ice cream is by no means complete and the student will get the necessary additions in the course in chemistry. When ice and salt are mixed, the ice is melted more rapidly on account of the attraction of the salt molecules for the ice molecules. The warm room can supply heat to the ice at a certain rate, but, since the salt hastens the melting of the ice, the heat to do this melting must come from the mixture itself. Also, since the salt is going into solution with the water, the

heat necessary to do this must come from the mixture. The effect of the salt then is to cause the ice to melt more quickly than it would melt by the heat from the room alone. Since the heat to produce these two effects comes largely from the mixture, there must be a lowering of its temperature. When this mixture is used to freeze ice cream, part of the heat, which before came from the mixture, is now supplied by the ice cream and it is frozen.

148. Vaporization.—The passage of a substance into the gaseous or vapor state is called vaporization. There are four types of vaporization:

1. Evaporation.
2. Ebullition—boiling.
3. Sublimation.
4. Spheroidal state.

149. Evaporation.—By this is meant the vaporization of a liquid taking place slowly from the free or exposed surface. It is probable that all liquids evaporate at all temperatures, but we know that at the same temperature the rate of evaporation of different liquids differs greatly. Ether, gasoline, alcohol, water, kerosene illustrate the decreasing rate of evaporation when all are at the same, the room, temperature.

The factors upon which the rate of evaporation depends are:

(*a*) Nature of the liquid.
(*b*) Temperature of the liquid.
(*c*) Area of the free exposed surface.
(*d*) Pressure on the free surface.
(*e*) Removal of the vapor over the surface.

The vinegar jug can be left uncorked without serious loss, while the perfumery or cologne bottle cannot. Gloves washed in gasoline dry much faster than those washed in water. A pan of water at room temperature may lose by evaporation 1 oz. of water per hour, and, if so, its loss at 100° F. would be about 3 times greater. The dishes rinsed with boiling water dry more quickly, on standing, than when the water was warm only. Clothes left in the basket dry very slowly, while the garment spread out so as to have a large free area dries quickly. The pail of water thrown on the porch on a hot day disappears

in a few minutes. Another interesting illustration of the effect of area on evaporation is furnished in the roasting of meat. An 8-lb. roast is put into an oven whose temperature has been adjusted so as to sear the meat in a short time, thus reducing the amount of evaporation and consequent loss of the juices. Now a 2-lb. roast of meat has twice the surface exposed per pound that the 8-lb. roast has, and so, unless the temperature is much higher at the start, the smaller roast will be the drier. Every laundress is delighted with a windy day for clothes drying, and the home candy maker has the kettle uncovered so the vaporized water may not remain over the cooking sugar. The water-soaked ground is soon dry under the action of the wind, and shrubbery, flowers and lawns quickly show the loss of moisture after a windy summer day.

150. Explanation of Evaporation.—Why liquids evaporate is easily seen if we consider our theories of matter and heat. We assume that liquids are composed of molecules which have certain attractions for each other, that at all temperatures above $-273°$ C. these molecules are in constant motion, moving around something like a bottle full of angry bees. At any given temperature the velocity of the individual molecules is not the same, but the *average* velocity is always the same for the same temperature. Each molecule, like the angry bee, in its constant and rapid migration, suffers bumps or impacts with its fellows, thus, for a time, gaining in velocity or losing velocity as a result of the impact.

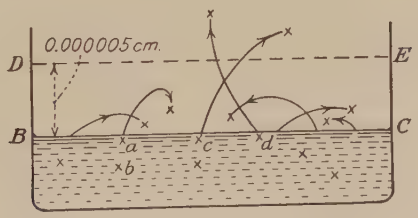


FIG. 80.—Evaporation of a liquid.

Let a vessel A be filled with a liquid to BC and be at a temperature t. Since the evaporation, the escape of the molecules from the liquid, does not take place all at once,

there must be some critical condition necessary for a molecule to get away. Consider molecule a by virtue of an impact from molecule b to have received a velocity greater than the average velocity of its fellows and in the direction indicated. Its motion would be retarded by the attractions of the other molecules, which attraction we assume to reach above the surface of the liquid to the lower level DE. If this attraction finally slows up the molecule sufficiently, it will not escape or get beyond the DE region and so will fall back into the liquid. But if c by reason of impacts gains a greater velocity than a, it can escape or evaporate. What is the effect on the molecules left? If there were n molecules in the vessel, of mass m and average velocity v, the average energy of a molecule would be

$$\tfrac{1}{2}mv^2 = \text{kinetic energy},$$

but the one molecule escaping carried more than its share of the energy, so after its escape the average energy per molecule left is

$$\tfrac{1}{2}m(v - x)^2,$$

a quantity less than that represented above. Since the average velocity of the molecules is now less, the temperature of the liquid must fall unless outside heat is supplied to the liquid.

Evaporation is the process whereby a liquid passes gradually into the gaseous state by the projection of molecules from the free liquid surface into the region above this surface. It involves a loss of heat energy by the liquid. This cooling by evaporation is very familiar. Why do we fan ourselves? Why is perspiration a help to cooling our bodies? Why wrap the cake of ice in a *wet* sack when it must be kept for some time? We have seen that a molecule must have a certain velocity before it can evaporate. If the temperature of the liquid in A is higher to start with, then the average velocity of all the molecules is higher and fewer, impacts, or less violent ones, will be necessary before a molecule can escape. Hence more molecules will evaporate in a given time as the temperature of the liquid is raised.

If the vessel *A* had four times the area, it is evident that under the same conditions more molecules would escape and the rate of evaporation would increase. In hot countries unglazed jars of fairly large surfaces are filled with water and the thin film of water evaporates rapidly from the large surface and cools the water in the jar.

Lastly, let us consider the evaporation in a closed vessel. The molecules that escape from the liquid are not now carried away but remain in the region above. The vapor molecules in the air or the region above the liquid, move about and experience impacts in exactly the same way as the air molecules, with the result that some of them find their way back into the liquid. Now as evaporation goes on from the liquid, the region is so filled with the water molecules that the number going back into the liquid is equal to the number leaving the liquid. This is the condition called saturation. From the nature of the process it can be seen that the number of molecules necessary to saturate the air will depend on the temperature, the higher the temperature the greater the number of molecules of vapor needed. The converse is also true. When air is saturated at a given temperature, a fall in temperature will make necessary the return to the liquid state of a certain number of molecules.

All rain, snow, and dew come first from the evaporation of the water on the earth. The air, when warmed by the sun, can hold this water vapor, but when for any reason the air becomes cooled, it first becomes saturated, then, if the cooling continues, the vapor is deposited in the liquid state as rain, dew, or snow.

Study Exercises

1. If clothes could be hung on the line to dry while hot, would they dry more quickly? Why?
2. Why is moisture frequently deposited on the windows of the laundry but not on the inside walls?
3. Will more heat be necessary to bring water to a boil in an open vessel than in a covered one?
4. Why should a "cloud" appear at the mouth of a teakettle when a window is opened?
5. Why does cologne cool the head more than water?

6. Why do we not "see our breath" on warm days?
7. Why does a cold room frequently feel damp?
8. Why does a draft of air when we are overwarm, chill us?
9. Will wrapping a piece of ice in wet sacking or paper cause it to melt less rapidly than if wrapped in the same materials dry? Why?

151. Ebullition or Boiling.—The phenomena of boiling are familiar to nearly every one. When heat is applied to a pan of water, bubbles of air begin to form on the bottom, and later on the sides of the pan. They grow larger and larger until finally they become detached from the pan and rise to the surface and disappear. These bubbles are followed by smaller bubbles, now nearly all on the bottom, which seem to rise and fall and to move about near the bottom. As the bottom becomes more or less completely covered with them, a little noise can be heard. Continued heating soon causes some of the bubbles to leave the bottom and attempt to rise through the liquid, but they disappear before getting to the surface. This movement of the bubbles upwards increasingly continues with a singing or simmering note, due to their collapse in the colder layers of water above the bottom. The pitch of the note increases until the bubbles get nearer the surface before collapsing, when the sound gets softer. When the bubbles break at the surface, the noise is very much less. The water is now boiling.

The temperature of the water, as heat was supplied, has been steadily rising, and so the rate of evaporation has been increasing. A condition is soon reached where the surface of the liquid cannot afford the means for the sufficiently rapid escape of the molecules and then bubbles of vapor are formed within the liquid and rise to the surface. When these bubbles escape from the surface, boiling has begun and the temperature becomes stationary. If more heat is supplied, the rate of formation and escape of the bubbles is increased, but no rise of temperature takes place. There is evidently, then, at the boiling point of a liquid, an equilibrium between the heat gained by the liquid and the heat lost by the liquid.

The boiling temperature of a liquid is very greatly modified by pressure. The bubbles of vapor cannot form in the liquid

until the pressure of the vapor is at least as great as the external pressure on the surface of the liquid. If the external pressure is increased, then a higher temperature and more heat energy are required to vaporize the liquid in the interior, and if the pressure is lowered outside, a lower temperature and less heat energy will vaporize it. At 100° C. water boils when the pressure on it is 76 cm. because the pressure of the vapor is then 76 cm. too. But under an external pressure of 45 cm. water will boil at 83° C. When a liquid, as water, is confined in a closed vessel, it may be heated far above the usual boiling point, the external pressure on the surface of the liquid becoming very great due to the pressure of the steam. If, now, the heat supply is continued until the liquid has absorbed all the heat necessary for its vaporization, it will, unless the vessel is very strong, explode, for 1 cc. of water when vaporized in air occupies about 1,700 cc. of space. It would not be safe at all to heat water in closed vessels to the boiling point were it not for the fact that to convert 1 g. of water into vapor requires a large amount of heat and this is, under ordinary conditions, a very slow process.

The boiling point is modified by the nature of the material of the vessel, the roughness or smoothness of the walls, and the absence of dissolved gases in the liquid. The water in a metal vessel may start to boil as much as 3° C. below that in a glass vessel. Glass beads, tacks, or other small solid particles thrown into a vessel of water may change the boiling point by 1° C. If air-free or gas-free water is boiled, its temperature may rise much above the boiling point and when it does vaporize, it may do so with explosive violence. The familiar bumping is an effect due to the absence of sufficient dissolved gas in the liquid, while the "furred" condition of the teakettle bottom acts partly like the tacks or glass beads.

For these reasons, and because the pressure of the vapor bubble in the liquid is actually greater than the external pressure due to the pressure of the water above it and its own surface tension, the true boiling point of a liquid is not found by putting the thermometer in the liquid, but by suspending it in the vapor above the boiling liquid. The bubble, when it

breaks at the surface, expands and so cools down to the true boiling temperature.

The boiling point of solutions is higher than the boiling point of the pure liquid. The effect of the dissolved substance is to lower the vapor pressure of the liquid, and so a higher temperature is necessary to produce the equilibrium between the vapor pressure and the external pressure.

Some liquids, of which the fats, butter, lard, olive oil, etc., are examples, have no boiling point. The vapor pressure within is always less than the external pressure and the continued application of heat results in an increasing rise of temperature until finally the substance is decomposed or carbonized.

152. Latent Heat of Vaporization.—The change from the liquid to the gaseous state is, as in the case of melting, a heat absorbing process. Work must be done in separating the molecules and the amount is much greater than in the melting of solids. The work done by the heat energy supplied is stored up in the molecules in the form of potential energy. In the case of water at 100° C., 537 cal. are required to vaporize 1 g., or the work done is the equivalent of raising a 1,000 g. mass vertically a distance of 229.3 m. The *latent heat of vaporization is defined as the amount of heat necessary to vaporize unit mass of a liquid.* Since probably all liquids are passing over into the gaseous state at all temperatures, the latent heat has not a fixed value even for a given substance, but its value depends upon the temperature at which the vaporization is taking place.

Regnault has shown from his experiments that the following equation holds fairly well for water:

$$\text{Latent heat} = 606.5 - 0.695t.$$

where t is the temperature in degrees Centigrade at which the vaporization is taking place. If $t = 100°$ C., the equation gives 537, that is 537 cal. are required to vaporize 1 g. of water at 100° C. When 1 g. is vaporized at 50° C., 571.8 cal. are required, while at 120° C., only 523.1 cal. are necessary.

In an *uncovered* vessel, the water is leaving the vessel in the form of vapor long before it boils. For each 5 drops of water thus leaving the vessel, enough heat is taken away to cool 1 lb. of water 1° F. A *covered* vessel is evidently a conserver of the heat.

If a vapor at its boiling temperature condenses to a liquid, the potential energy of the molecules is given out in heat energy as they unite to form liquid molecules, and hence the heat liberated is equal to the heat absorbed in the vaporization process. Steam heating is evidently the most familiar example of this process. The latent heat of vaporization of water at 212° F. is 966 B.t.u. per pound.

SOME LATENT HEATS OF VAPORIZATION

	Calories per Gram	British Thermal Units per Pound
Water	537	966
Alcohol	205	370
Ammonia	297	534

153. Sublimation.—Some solids, notably camphor, ice, and snow, pass directly from the solid into the vapor state. A lump of camphor will have its size reduced noticeably in a few hours. Snow vanishes without melting. As we have found heat absorbed in the change from the solid to the liquid and the liquid to the gaseous states, so we may look for an absorption of heat in sublimation; and we have also a latent heat of sublimation which is equal to the sum of the latent heats of fusion and vaporization of the substance. The "smelling salts" are examples of solids which sublime.

154. Spheroidal State.—An interesting type of vaporization is that known as the "spheroidal" state. Every one has witnessed the peculiar behavior of a drop of water on a hot stove. When a drop of water falls on a hot stove it may boil very violently with a hissing noise; but if the stove is hotter, the drop does not boil or spread out on the lid, but rolls around like a drop of mercury. The phenomenon is also frequently seen for a shorter time when a drop of hot syrup

from a pie strikes a very hot surface, or the drop of fat dances on the surface of very hot soup or cocoa.

Experiment shows that the rolling drop is at a temperature below 100° C. and is not in contact with the heated surface, but is supported on a cushion of its own vapor. The heat necessary for it to vaporize comes very largely from the hot vapor below it. But the heat from the vapor is supplied slowly, and so the drop requires a longer time to vaporize than it would if in contact with the hot stove. The spheroidal state is sometimes seen when the laundress tests the temperature of the iron by putting a drop of saliva on it; and the expert candy maker makes use of the protection of the water vapor when he wets his finger before putting it in the boiling syrup.

155. Cooking under High Pressures.—The "Denver Cooker" is an application of the fact that an increase in the pressure raises the boiling point of a liquid and the temperature of the steam. The cover of the cooker (Fig. 81) can be securely clamped on and safety is secured by means of a safety valve which will allow the steam to escape whenever the pressure reaches a value of about 27 lb. per square inch. The temperature in the cooker when the pressure gage reads 15 lb. per square inch is 100° C., at 20 lb. per square inch 110° C., at 25 lb. per square inch 116° C., and at 27 lb. per square inch 117° C., approximately. In cooking certain foods, a high temperature is desirable and this high temperature also lessens the time of cooking. Potatoes, for example, can be cooked in 10 min. in such cookers. In Denver and other places located at high altitudes, water boils at a temperature below 100° C. with a resulting disadvantage in some cooking operations. The pressure cooker enables the housewife to overcome this.

Fig. 81.—Pressure cooker.

The magazines have made everyone familiar with the "food shot from guns," puffed wheat and puffed rice. The production

of these articles is another illustration of high pressure cooking. The wheat or rice is placed in metal cylinders and tightly sealed. Each cylinder with its pressure gage is placed in an oven and heated at about 350° F. The water in the wheat or rice is partly changed into steam and cooks the cereal. Now when the pressure is high enough, the cover is quickly removed, and the superheated water in the starch granules changes into steam, producing an explosion in the granule which expands it.

The process of producing dry milk, dehydrated vegetables and fruits is the reverse of the one just described. In this process, the substance is under a low pressure, less than that of the atmosphere, and so its boiling point is below 100° C. One of the advantages claimed for this method is that while the water is removed, little or no chemical changes are produced in the food.

Illustrative Problems

1. Twenty quarts of punch, specific heat 0.99 at 60° F. are to be cooled to 36° F. by ice in the bowl. How much ice will be needed? Twenty quarts (40 lb.) cooled 24° will absorb $40 \times 24 \times 0.99$ or 950 B.t.u. Heat of fusion of ice is 144 B.t.u. The melted ice is to be raised from 32 to 36°.

Hence $950 = (144 + 4)X$, where X = number of pounds of ice needed. $X = 6.3$ lb.

2. How many pounds of steam at 212° F. and cooling to water at 192° F. will be required to give a room 12,000 B.t.u.? One pound of steam condensed to water at 212° will give out 966 B.t.u One pound of water cooling from 212 to 192° will give out 20 B.t.u.

Therefore,

$$\frac{12{,}000}{966 + 20} = \text{number of pounds of steam necessary.}$$

3. One pint of water is to be evaporated from a fruit jam at 212° F. How much heat will be required? Latent heat $= 606.5 - 0.695t$ where t is in degrees Centigrade and 1 pt. or 1 lb. of water equals 454 g. The latent heat equals 537 cal. per gram.

Therefore,

$$537 \times 454 \text{ cal. will be required} = 243{,}798 \text{ cal.}$$

Study Exercises

1. Why is the burn from steam worse than from boiling water?
2. When food is being cooked in boiling water, what are the advantages or disadvantages, if any, of violent or vigorous boiling?

3. Which type of cooker, a high or low pressure cooker, would be better in candy making?

4. Why does corn pop? Would you expect very old corn to be satisfactory?

5. It is claimed that a baked potato is more mealy if broken open quickly rather than cut open. Can you see any reason for the claim?

6. On damp days, it is said, an oven will heat to the required temperature more quickly if, a minute or two before the heat is on, the oven door is opened wide for a short time and then closed. Can you see why this might be so?

7. Do you think a cereal will cook more quickly in a double boiler when the inner vessel is nearly surrounded with steam or when surrounded by boiling water?

8. The hot water leaving a steam radiator may be at the same temperature as the entering steam. How is the room receiving heat?

9. A fall of 1° C. in the boiling point is caused by rising about 960 ft. above the earth's surface. Denver is 5,000 ft. above sea-level. What is the temperature there of boiling water?

10. Two pounds of ice are changed into steam at 212° F. How much gas, using a burner 50 per cent efficient, will be consumed?

11. Why are electric fans desirable additions to the living rooms in summer, but not in winter?

12. In a steam radiator 5 lb. of steam condensed every hour. How many pounds of water cooling from 180 to 110° F. in a hot-water radiator would give the same amount of heat to the room?

13. If 1 cu. ft. of air weighs 0.08 lb., how many cubic feet would have to leave a hot air register, falling in temperature from 180 to 65°F., to give the room the same amount of heat as in Exercise 12?

14. A 6-qt. teakettle had the water in it raised from 50 to 212° F. and then 1 qt. of water boiled away. What horsepower engine working for 10 min. and having its work all converted into heat would be necessary to produce the same amount of heat?

15. In an Oriental water cooler holding 2,000 g. of water, 5 g. of water per minute were vaporized from the outside walls. If we neglect the inflow of heat from the outside, what was the fall of temperature per minute of the water in the jar?

156. Production of Artificial Cold or Mechanical Refrigeration.—The commercial production of the so-called artificial ice has made such advances that we find it not only in places where natural ice cannot be produced but even competing successfully with the natural ice.

There are a number of different systems in use for the production of cold and the one described here uses liquid ammonia as the refrigerant.

Liquid ammonia is contained in a tank A under a pressure of from 125 to 175 lb. It is allowed to flow through the expansion valve V into a series of coils immersed in brine in the brine tank. The liquid ammonia, absorbing heat from the brine, is vaporized and then passes into the pump compressor which compresses the gas so that on passing into the coils in the cooling tank, through which cold water is constantly running, it is condensed to a liquid. It then passes into A and the cycle of operations is repeated. As the operation continues, the brine becomes cooler and cooler and the water which is placed in vessels immersed in the brine finally become frozen.

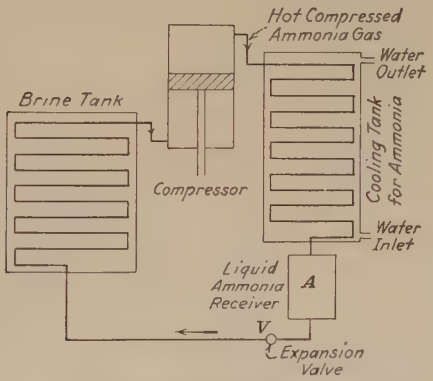


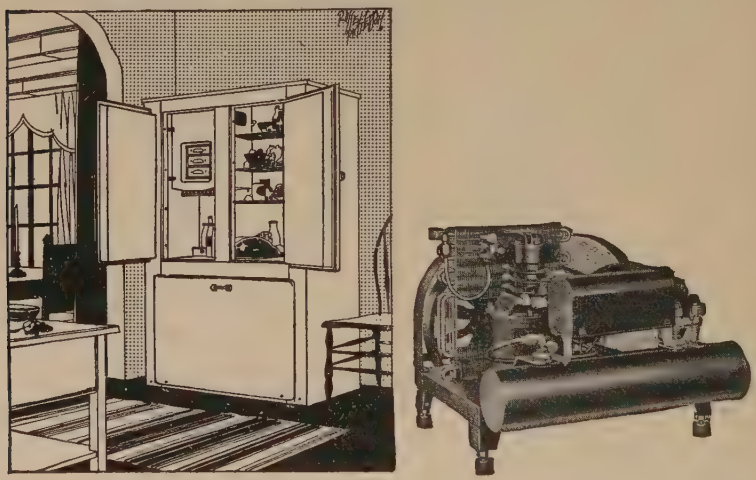
Fig. 82.—Sectional view of a refrigerating machine.

Neglecting some factors which need to be considered in the actual working of an ice machine, let us find out how many pounds of liquid ammonia must be vaporized to freeze 1 lb. of water at 32° F. The heat of vaporization of liquid ammonia is 492 B.t.u. per pound, and the heat of fusion of water is 144 B.t.u. per pound. Hence, 144 B.t.u. must be taken from the water to freeze it and this heat will vaporize 144/492 of 1 lb. of liquid ammonia, or whenever 1 lb. of liquid ammonia has changed from a liquid to a gas, the surrounding system has given up 492 B.t.u.

The small refrigeration machines in refrigerator cabinets are being increasingly used in the home. They are in principle the same as the larger ammonia machines except that in the

place of ammonia, liquid sulphur dioxide or ethyl chloride is used.

Mechanical refrigeration is used not alone for making ice, but for producing cold for many other purposes. In many hotels, office buildings, hospitals, etc., all the drinking water is thus cooled. Many of the large ice-cream plants use it both for freezing the cream and for hardening it. Skating rinks with the floors laid with brine pipes and then covered with water are in use in several American as well as Euro-



(*a*) (*b*)

FIG. 83.—(*a*) An electric refrigerating cabinet. (*b*) The air compressor, goes in the base of the cabinet.

pean cities. But perhaps to the housewife its use to keep foodstuffs from spoiling for longer or shorter periods is its most interesting application. We have grown accustomed to having our homes maintained at a constant temperature in the winter months, but rather expect to suffer from heat during the summer months. However it is possible now, as shown by its use in some theaters and public buildings, to have the home cooled to a comfortable temperature in the summer. It is largely a question of our willingness to pay the price, which at present is excessively high. Perhaps when we have com-

munity heating, as we have the lighting and the water supply, we may have also the community cooling of our homes. If we assume that to maintain a given room 20° F. below the outside temperature will require 5,000 B.t.u. per hour, the amount of ice to be melted and the cost may be found approximately. In melting, 1 lb. of ice will absorb 144 B.t.u. and the melted ice water will aborb 30 to 40 B.t.u. more, making a total of 180 B.t.u. per pound of ice. To absorb 5,000 B.t.u. will require the melting of about 28 lb. of ice per hour and at $0.50 per hundredweight for the ice, the cost would be about $0.14 per hour.

Some Suggested Laboratory Exercises

1. Determination of the melting point of lard, butter, suet.
2. Study of Thermos-ware appliances, using the heat of solidification.
3. Ice and salt freezing mixtures of different proportions.
4. Heat of vaporization of water.
5. Study of evaporation in vessels of different sizes, different material and covered and uncovered.
6. Relation between temperature and time of cooking in a pressure cooker.
7. Losses due to evaporation in cooking. Different ovens.

REVIEW SUMMARY

Change of state always involves an absorption or liberation of energy. When heat energy is absorbed it is transformed into potential energy. When there is a liberation of energy or a change of state, the energy comes from the potential energy in the body.

Crystalline bodies have a sharp melting point, while non-crystalline bodies do not.

Change of state involves a change in the volume of the body. Solids, in general, expand when they melt. Ice is one of the exceptions. Pressure applied to a solid which expands on melting causes a raising of the melting point.

Melting points of metallic alloys are lower than the melting points of any of the metals in the alloy.

Latent heat of fusion of a substance is the number of heat units required to melt a unit mass of the substance. For water, it is 80 cal. per gram or 144 B.t.u. per pound.

Heat of solution is the amount of heat required to dissolve unit mass of a substance.

Freezing mixtures, ice mixed with various salts, such as rock salt, KCl, NH_4Cl, $CaCl_2$ etc., produce low temperatures, from 12 to $-58°$ F.

Evaporation is the slow vaporization from the free surface of a liquid. The factors which determine the rate of evaporation are: the nature of the liquid, its temperature, area exposed, pressure on the surface, rapidity of removal of the vapor above the surface.

Mechanical explanation of evaporation.

Boiling or ebullition is the process of vaporization by bubble formation.

Boiling point of a liquid is the temperature at which the vapor pressure is the *same* as the outside pressure on the liquid.

Heat of vaporization is the amount of heat to change unit mass of the liquid into vapor. For water this is 537 cal. per gram or 966 B.t.u. per pound.

Pressure cookers.

Production of artificial cold. Refrigerators.

CHAPTER XVI

DISTRIBUTION OF HEAT

157. Ways of Distributing Heat.—Everyone is familiar with the fact that heat may be communicated from one body to another at a lower temperature or transferred from one part of space to another. There are three methods for producing this transference of heat: convection, conduction, radiation.

158. Convection.—Convection is the transfer of heat by the actual movement of the heated body. It can occur only in liquids and gases. The movement results from a difference in density of the cold and the warm fluid. The air in contact with stove or radiator is heated and expands, thus becoming less dense or lighter than the cold air. Therefore, it rises, while the colder air comes in from the sides to take its place. The warm air constantly rising from the source of heat moves to various parts of the room, distributing the heat.

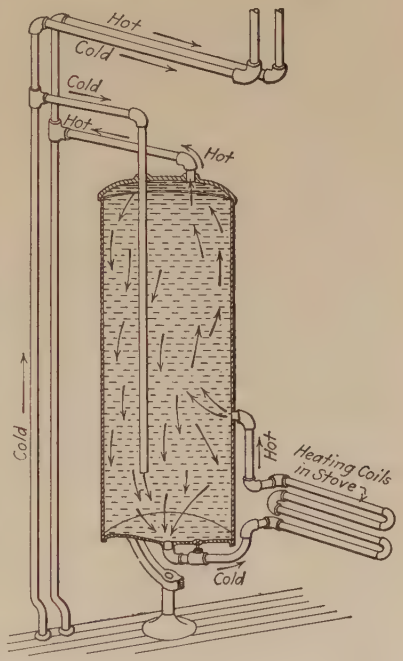


FIG. 84.—Convection currents in a hot-water tank.

The factors upon which the amount of heat transferred by convection depends are:

(*a*) The difference in temperature between the hot and the cold parts of the medium.

(*b*) The specific heat of the medium.

(*c*) The coefficient of expansion of the medium.

(*d*) The viscosity or fluid friction.

(*e*) The size and other conditions of the channels through which the medium moves, as in hot-air heating systems.

Air and water as convectors of heat will be compared, since both are used in heating the home.

	Relative values		Advantage with
	Air	Water	
(*a*) Difference in temperature in the medium	60	10	air
(*b*) Specific heat	1	4	water
(*c*) Coefficient of expansion	20	1	air
(*d*) Viscosity	1	80	air

If a given hot-water radiator satisfactorily warms a room when 1 cu. ft. of water passes through the radiator per minute with a temperature change of 10° F., then the B.t.u. given out will be, $63 \times 1 \times 10 = 630$ B.t.u. To obtain the same amount of heat from air would require 4,000 cu. ft. if the same temperature difference is used.

Distribution of heat by convection finds many illustrations in the home apart from the heating system. In cooking, the heating of liquids is chiefly brought about in this way and convection is the chief factor in heating the oven of the kitchen range, in disposing of the heat of combustion in the kerosene lamp, in the ventilation of rooms, in cooling food in the refrigerator, and in the loss of heat from closed liquid-filled vessels. The coffee pot loses, perhaps, three-fourths of its heat by convection, and a teakettle on a stove in a strong draft may not have the water in it brought to the boiling point.

159. Conduction.—Conduction of heat is the transfer of heat from particle to particle and thus from one part of a heated body to another. It involves no actual transfer of the heated matter, as in convection, and, also, unlike convec-

tion, is not influenced by a change in density or gravity. The mechanism of conduction is not certain, but it probably takes place as follows: When one end of a bar, for example, is heated, the molecules are made to vibrate more violently and, as they continue to increase their intensity of vibration, they send out energy in the form of ether waves, which, falling on the near-by molecules, cause them to vibrate more violently. After an interval these molecules, like the first, become sources for sending out energy in waves to other molecules in front of them. Thus the heat energy is transferred from one portion of a body to another by a process of sending out waves whose energy is first absorbed and, then, in turn, sent out to the molecules farther and farther distant from the source of heat. It is very probable that some of the heat energy is also transmitted by the impacts between the molecules.

That different substances have far different abilities to conduct heat is familiar to all. The solid silver spoon gets uncomfortably hot in the cup of coffee, while the wooden spoon in the jelly kettle is hardly warm. It may be hard to convince one's self that the bare floor and the woolen rug are at the same temperature when a bare foot steps on them, yet the seemingly great difference in their temperatures is due to the difference in their conducting abilities. Solids, while differing greatly among themselves, are the best conductors, liquids are next in order, and gases are the poorest.

The factors upon which the amount of heat transmitted by conduction depends are:

(*a*) Kind and nature of substance.

(*b*) Difference in temperature between the hot surface and the cold surface.

(*c*) Time the heat is transferred.

(*d*) Area of the path through which the heat is being transferred.

(*e*) Length of the path.

We may, for help in computing the amount of heat conducted, put these factors in their proper relations into an equation of the form:

$$H = \text{amount of heat conducted} = k\frac{A(t - t_1)T}{L}$$

where

k = the factor due to nature of the substance and is called the coefficient of conductivity.
A = the area in square centimeter.
t, t_1 = temperatures Centigrade at the hot and cold faces, respectively.
T = time heat was being transferred, in seconds.
L = length of the path in centimeters.

The coefficient of conductivity, k, is equal to H when all the other factors in the above equation are unity. Or k is the amount of heat in calories conducted in 1 sec., across opposite faces of a body 1 sq. cm. in area and 1 cm. thick, when the temperature difference between the faces is 1° C.

CONDUCTIVITIES OF SOME SUBSTANCES

	Calories		Calories
Aluminum	0.504	Air	0.00005
Copper	0.918	Flannel, wool	0.00013
Silver	0.978	Cotton batting	0.00004
Iron	0.144	Silk	0.000095
Tin	0.155	Paper	0.00032
Nickel	0.142	Vulcanite	0.00042
Glass	0.0024	Oak	0.0005
Porcelain	0.0022	Pine	0.0003
Granite ware	0.0017	Concrete	0.0022
Cork	0.00013	Ice	0.005
Asbestos paper	0.00045	Sawdust	0.00012
Cork carpet	0.00026	Water	0.0014
Linoleum	0.00036	Feathers	0.000057
Felt	0.000076		

Illustrative Problems

1. A window glass is 100 by 100 cm. and is 0.3 cm. thick. The outside temperature is 0° C. and the room temperature is 20° C. (68° F.). How many calories are conducted through the window each hour?

$$H = 0.0024 \frac{10{,}000(20 - 0)60 \times 60}{0.3} = 5{,}760{,}000 \text{ cal.}$$

$$= 22{,}857 \text{ B.t.u.}$$

2. A kitchen floor 300 × 400 cm. is covered with linoleum 0.4 cm. thick. The top surface was 20° C. and the bottom surface 10° C. How much heat was lost through the floor in 1 hr.

$$H = 0.00036 \frac{400 \times 300 \times 10 \times 3{,}600}{0.4} = 3{,}888{,}000 \text{ cal.}$$

3. Find the coefficient of conductivity of wool flannel from the following data. Area of the flannel 100 sq. cm., thickness 0.1 cm., temperature of top surface 37° C., of the bottom surface 20° C., time of flow of heat 1 min. and amount of heat conducted through the flannel, 132.7 cal.

$$k = \frac{H \times L}{A(t - t_1)T} = \frac{132.7 \times 0.1}{100(37 - 20)60} = 0.00013.$$

160. Conductivity and Our Temperature Sense.—Mention has already been made of the difference in our sensations when touching the floor and the rug. Metals in winter feel colder than wood or cloth and in summer they feel warmer. The ebony handle on the coffee pot always feels cooler than the metal sockets in which it rests. The explanation of these phenomena is in the differences of the conductivities. The better conductor, metal, carries the heat away from our hand more quickly when cold and carries heat to our hand more quickly when hot, than the poor conductors, wood, cloth, etc. Everyone knows the difference in our sensations in the winter when linen sheets are used in place of woolen ones. The use of "holders" to handle hot vessels finds its explanation in the slowness with which they take up heat and impart it. They are poor conductors. The paper-bag cooking method finds a part of its advantage in the poor conductivity of the paper, with resultant slowness in taking in or giving up heat.

161. Air as an Aid in Poor Conductivity.—A rather loosely woven sweater may be a good protection from the winter's cold on a quiet day, but is found to be very uncomfortable on a windy day. A wool batting quilt keeps in more heat than a woolen blanket of the same weight. A snow house is much to be preferred to an ice house. The vines and other shrubbery around the house are amply protected from the zero weather if covered with snow. Many substances, like fur, feathers, felt, batting, and sawdust, owe a large part of their poor conductivity to the entangled air which they hold. The table

shows the very low conductivity of air and if the substance is of such a nature as to entrap large amounts of air in it, not allowing the air to circulate and carry heat by convection, then it becomes a very good insulator or has poor conductivity. Our modern fireless cookers had their forerunners in the Norwegian hay cookers, boxes packed rather loosely with hay in which the hot vessel was placed. A cooker made from our modern baled hay, with less air between the spaces, would not be nearly as efficient. If fashion should decree that kid gloves should fit loosely they would be far warmer, and a loose under garment would give better protection than a glove-fitting one.

162. Radiation.—All bodies at temperatures above $-273°C.$ are sources from which ether waves are sent out continually. All bodies are then being cooled, since they are losing heat energy which appears as energy of wave motion. The ether serves for the transference not of the heat energy, but of the energy which was transformed from the heat energy into the energy in the wave motion. So the medium, the ether, is not heated. If a hot and a cold body were placed some distance apart in an enclosure from which all the air had been removed, convection and conduction could not take place in any heat transfer; yet after a time the cold body would be found to have gained heat and the hot body to have lost heat, and both would be at the same temperature. The cold body was heated by radiation. The ether waves carrying their energy of motion were stopped and absorbed by the cold body and this body had the vibrations of its molecules increased from the energy in the ether waves. It is only, then, when ether waves are wholly or partly retarded by some body and their energy transformed into the energy of vibration of the material particles, that this energy becomes apparent as heat. When two bodies are at different temperatures we do not regard the hot body as the only source of radiations, but that both are sending out radiations or ether waves, and that the hotter body is losing more heat by radiation than the colder one. When their temperatures are the same they are losing and gaining heat by radiation equally.

163. Source of Ether Waves.—Waves are set up in any medium whenever there is a vibrating body. The vibrations of the needle on the phonograph set up waves in the air. The vibrating molecules, or perhaps the smaller particles of which molecules are composed, set up waves in the ether. These waves travel in the ether of space with a velocity of 186,000 miles per second, or 3×10^{10} cm. per second. If the wave length of a heat wave is 0.00,008 cm., then the number of waves sent out from a source in 1 sec. will be $3 \times 10^{10} \div 0.00008 = 3.7 \times 10^{14}$, and this represents the number of vibrations per second of the vibrating particles which causes the heat radiations. We know of ether waves of various lengths, but those usually called heat waves vary in length from 0.000076 cm. to 0.006 cm. We shall take up this matter more in detail under light, but need to note here that light radiations are like heat radiations except in the matter of wave lengths, and light radiations, on being absorbed by a body, heat it as do the heat radiations.

164. Properties of Heat Radiation.—1. *Heat radiations can be transmitted through a vacuum, but are absorbed to a greater or less degree by all substances.*

Pure water absorbs 90 per cent, approximately. Clear glass, while allowing light to pass through it, will transmit less than 10 per cent of the heat radiations. It is frequently used as a fire screen for this reason. Lamp black absorbs nearly 100 per cent of the radiant energy falling upon it, while polished silver absorbs but 3 per cent.

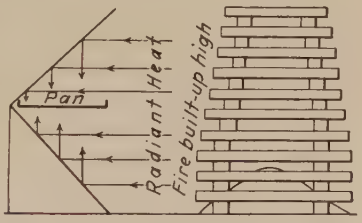


FIG. 85.—Cross section of a reflector stove.

2. *Heat radiations are transmitted in straight lines and are reflected from polished metal surfaces obeying the same laws as light.* It is because of this property that heat radiations can be distributed at will. When hot-water coils are placed under a window seat, it is usual to place a curved sheet of polished metal back of them and so curved as to reflect the radiations

out in a direction nearly parallel to the floor. Some modern ovens have the oven curved so as to direct the radiations downward on the food to be cooked. The different gas and electric radiant heaters nearly all give definite direction to the radiations by means of polished metal mirrors.

The reflector stove is one of the neatest illustrations of the use of directed heat radiations. The sketch is a cross-section view showing how the reflected radiations are used to do the cooking.

3. *The bodies which are good absorbers of heat radiations are also good emitters of the same heat radiations. Good reflectors are poor emitters of heat.*

If one holds the hand in front of the gas-burner flame, while opening and closing the air holes of the burner, it will be noticed that more heat is radiated to the hand by the yellowish luminous flame than from the bluish non-luminous flame, and this in spite of the fact that the luminous flame is some 200° C. cooler than the non-luminous flame. The luminous flame is found to be a good absorber of radiations and the non-luminous one a poor absorber. We find immediate application of this in the fireplace gas heaters. An opaque solid, a poor reflector, like asbestos, is heated by the flame and becomes the chief source of the radiant heat, giving out much more than could the hotter clear flame alone.

It is found by experiment that a teakettle with a *blackened* bottom will heat more quickly when placed on a wood or coal stove or when over the open flame than the kettle with a polished or unblackened bottom. But no such marked difference is found when the kettles are used on a gas stove. The kettle is heated very largely on the gas stove by the *contact* of the hot gases, while in the other stoves radiation plays the more important part and the black-bottomed kettle is the more efficient.

4. *The amount of radiant heat absorbed by a given body, the intensity of the radiations emitted being constant, varies inversely as the square of the distance between the absorbing and emitting bodies.*

If a person sitting 1 ft. from an electric heater, for example, receives a certain amount of radiation, at 2 ft. distant the amount would be one-fourth as great.

165. Law of Cooling.—Newton's law of cooling states that the rate of cooling of a hot body is proportional to its *excess* temperature over that of the surrounding medium.

If a kettle of hot water at 100° F. is found to cool in air at 70° with a temperature drop of 1° per minute, then the drop in temperature per minute when the kettle is at 110° F. can be found as follows:

$$(100 - 70) : (110 - 70) :: 1° : x^0.$$

$x° = 1.33°$, the drop in temperature per minute.

In the laboratory problem on conductivity, you were instructed to have the water in the calorimeter 3° *below* the room temperature and to stop the experiment when the conducted heat had raised the temperature 3° *above* the room temperature. Can you see why the temperature change in the calorimeter was due solely to the conducted heat and not to heat gained from the room or lost to the room? Newton's law is approximately true only when the difference in temperatures are small.

166. Cooling of Bodies.—Melloni and others have shown that the rate at which heat is radiated from a body depends on:

1. Nature of the body.
2. Condition of the surface, as roughed or polished.
3. Temperature of the surface.

A dull surface of lampblack may be taken as having 100 per cent absorption and also when heated 100 per cent radiating ability. Unglazed white paper is nearly as good an absorber as lampblack. The dull stovepipe is a better absorber and radiator of heat than the polished iron stove pipe. In general, rough surfaces are better radiators than polished ones, and black surfaces than light ones. There seems to be no difference due to color alone. The part played by the temperature in radiation can be seen from the curves giving the energy radiated by blackened copper.

It is evident that radiation plays but a small part in the heat losses of a body below 100° C. Hold the hand at the side of a hot-water radiator, hand heated by radiation, then over the radiator, hand heated by convection. Hold the hand in front of the fireplace, which is much hotter. Do not the results agree with the facts shown by the curves? What would be the effect on loss of heat from gas ovens if made of white polished enamel instead of dull black iron? The radiating surface does not have to be very thick to exhibit very different radiations. A hardly visible film of lacquer has been known to increase threefold the radiation from a brightly

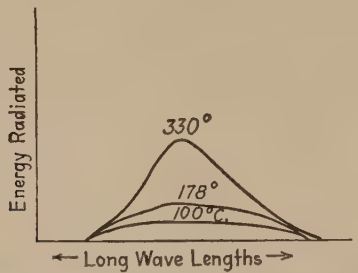


Fig. 86.—Radiation from blackened copper at different temperatures.

polished kettle of boiling water. Fire tongs and pokers when new sometimes show remarkable absorbing ability for the heat from the fireplace, but as the lacquer is worn off they absorb hardly enough to be noticeable. Hot-water and steam radiators, while all of iron or steel, and rough, may then show marked differences in their ability to radiate.

The actual cooling of most bodies is not due to radiation alone but to conduction, convection, and radiation. Contrary to the general belief, there is not so marked a difference between the loss of heat from a closed vessel in air when lampblackened and when polished. The lampblacked vessel cools only about one-eighth faster than the polished one.

The curves given below, taken from Franklin and MacNutt's "Physics," show strikingly the difference in cooling between a polished tea pot and a thermos bottle.

In the thermos bottle, *I*, radiation, convection and conduction are all a minimum, so the loss of heat is small.

In the teapot, radiation and conduction losses are small but convection loss is large, so the heat loss is large.

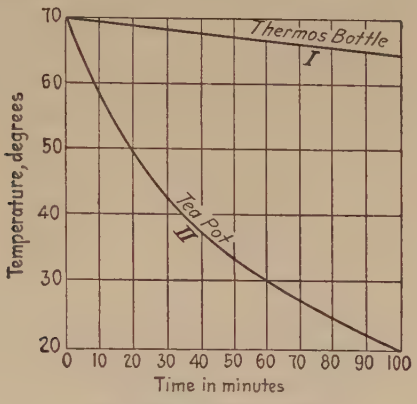


FIG. 87.—Cooling curves.

The table below shows the temperature fall in two similar vessels filled with hot water, one polished, the other covered with lampblack.

Time, minutes	Lampblack on nickel vessel, temperature	Polished nickel vessel, temperature
0	86	85.2
15	67.8	69.9
41	51.3	56.8
62	43.4	49.4
80	39.0	45.0
100	35	41.0

The lampblacked vessel lost about 15 per cent more heat than the polished vessel.

167. Study of Some Typical Household Appliances. (*a*) *Thermos Bottle.*—This container is designed to keep liquids hot or cold, that is, to prevent the loss of heat from within in

one case and the entrance of heat from without in the other case. It consists of two bottles, one inside the other, and connected only at the neck or top. The air is removed from the space between the bottles, and the inner surface of the outside bottle and the outer surface of the inner bottle are silvered. From the previous discussion of the methods of distributing heat, it will be evident that the bottle is a very poor conductor of heat, as the heat can get out only by travel-

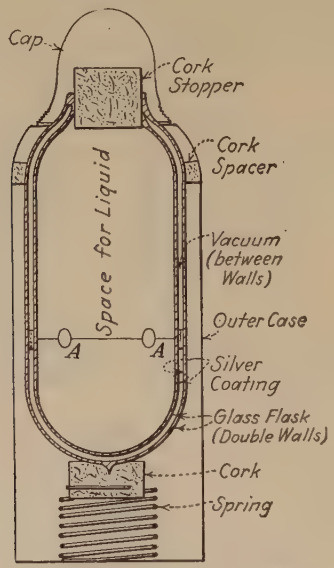


FIG. 88.—Thermos bottle.

ing the length of the inner wall to the top and then down the outer wall. The glass walls are very thin and so in terms of our equation for measuring conductivity, k and A are small and L is large, making H, therefore, small. Since there is no air between the walls, loss of heat due to convection is zero. With two polished surfaces, good reflectors, little heat will escape by radiation. The data given in the table will show the effectiveness of the thermos bottle and also give some idea of the part played by convection and radiation in the heat loss.

Thermos Bottle (1) Conduction, Convection, Radiation a Minimum		Thermos Bottle (2) Convection, Conduction a Minimum —Radiation a Maximum. No Silvered Surfaces		Thermos Bottle (3) Conduction and Radiation Minimum—Air between Walls. Convection Maximum	
Time, Minutes	Temperature, Degrees Fahrenheit	Time, Minutes	Temperature, Degrees Fahrenheit	Time, Minutes	Temperature, Degrees Fahrenheit
0	200	0	202.5	0	202
10	198.5	10	196	10	192
20	197	20	189	20	182
30	196	30	184	30	175
40	195	40	178.5	40	168
50	193.5	50	172	50	160
60	192.5	60	168	60	155

The data in (1) was obtained from a bottle with the protecting case removed. In (2) the bottle had no silvering to act as a reflector, so radiation was a maximum. The bottle in (3) had no vacuum between the walls and was open at both the bottom and top, so that convection currents could be established.

A new type of thermos bottle, called the "Ferrostat," has recently appeared. It is a double walled *all-metal* bottle with the inside enameled. Between the walls is placed a very finely divided powder and the vacuum between the walls is not as high as in the older type of bottle. This bottle is nearly as efficient as a conserver of heat, is a little heavier, but is *non-breakable.*

(*b*) *Fireless Cooker.*—The people in the north of Europe have used for many years a device known as the " Norwegian cooking-box." It has had a rapid development in this country during the last few years under the name of the "fireless cooker." It is, essentially, a box lined with some material which is a poor conductor of heat. Hay, straw, and excelsior were frequently used in the earlier forms, and the covering was cloth. The tightly covered vessel was placed in the hole and a cushion of the same composition was placed on top of the vessel. These early forms were as good, if not better, non-conductors

of heat than the metal-lined later types, as is shown by the data for cooker No. 1, which was manufactured over 18 years ago. But they were unsanitary. The modern types use felt, asbestos and other poor conducting material, which is placed in metal-lined boxes. By the use of heated stone radiators the range of possible cooking operations has been extended. When radiators are used, it is desirable that the cookers be

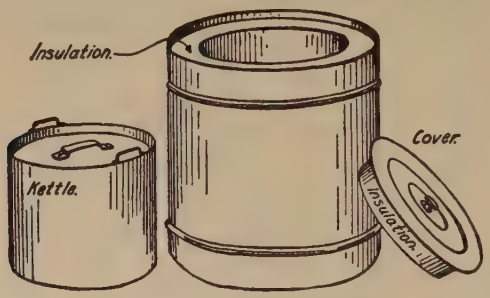


Fig. 89.—Fireless cooker.

equipped with valves which will permit the escape of the water vapor, thus making the baking or roasting operations more nearly comparable to the dry heat of the oven. The data given below show the loss of heat due chiefly to conduction and radiation for three cookers of different makes.

Cooker	Time, Hours	Temperature in the Cooker with 2 Qt. of Water, Degrees Fahrenheit
No. 1	Start	212
	3 hr	165
	4 hr	154
No. 2	Start	212
	3 hr	155
	4 hr	144
		With the Two Radiators Heated, Degrees Fahrenheit
No. 2	Start	430
	4 hr	220
No. 3	Start	448
	4 hr	225

(*c*) *Gas Stove Oven.*—The purpose of an oven is to cook the food placed in it, and all losses of heat from the oven by conduction, convection, and radiation tend to defeat this primary purpose.

Every housewife knows that when the average gas oven is in operation it is a good furnace for heating the kitchen. This large heat loss means that the ratio of the heat used in cooking to the heat put in is small or the efficiency is very low. An efficiency as low as 10 per cent is not uncommon. To increase

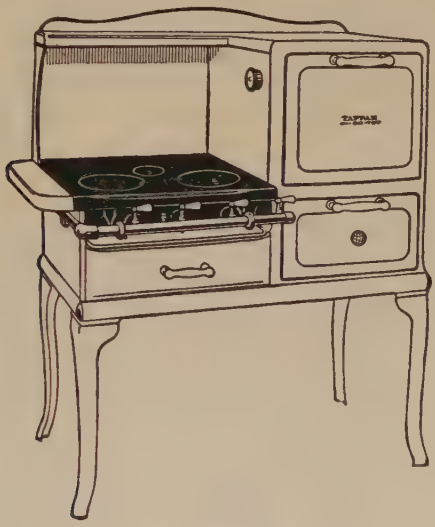


FIG. 90.—An insulated gas oven.

the efficiency, the oven should be a poor conductor and radiator of heat. But it is in practice, both a good conductor and a good radiator as shown by the temperature and by holding the hand near the side to receive the radiant heat. Good insulation or poor conductivity can be secured by putting more insulation in the walls, making them 2 or even 4 in. thick. Low radiation can be secured by not using rough dull black outside covering or perhaps by using a white polished enameled surface. The data given below will show the advantage of better insulating of the ovens. The oven used was a commercial

one and when used as purchased required 100 of the heat units to raise its temperature from 200 to 325° F., taking 80 min.

When the oven was placed in an asbestos lined box with 1½ in. of asbestos and 1 in. of air on all sides, the door side being unprotected, 54 units were required to raise its temperature from 200 to 400° F. in 30 min. To maintain this temperature for 40 min. required 32 units. The oven was finally placed in the same box with the air space filled with ground asbestos and magnesia. In 20 min. 35 heat units raised it from 200 to 400° F., and 20 more heat units maintained this temperature for 30 min.

In the second test, the oven temperature fell after the heat was cut off, from 400 to 200° in 35 min., while in the last test it fell from 400 to 200° F. in 60 min.

The makers of electric ovens, perhaps because of the relatively high cost of heating by electricity, are giving more and more attention to the insulation of their ovens. The following data for a modern electric oven show the value of the better insulation very clearly. One electric oven was raised to 478° F. and the current was then cut off. At the end of an hour the temperature was 300° F. and an hour later it was 235° F.

(*d*) *Refrigerator.*—The figure shows the methods used to make the refrigerator a poor conductor of heat or a good insulator. From the construction standpoint there are two objectives. The efficient refrigerator must be well insulated and it must be sanitary and easy to keep clean. Comparing different models of the same make will bring out the fact that, in general, as the cost of the refrigerator increases, the insulating qualities remain about the same, but the sanitary properties and ease with which it is kept clean are increased nearly in proportion to the increase of cost. But when different makes of refrigerators are compared, great differences in both these factors are found. Two different makes of refrigerators were tested; one maintained a temperature of 55° F. in the food chamber, or a difference of 15° between the inside and outside temperatures with a consumption of ice per day two and one-half times greater than the other. The second maintained a temperature of 48° F., or a difference between the inside and

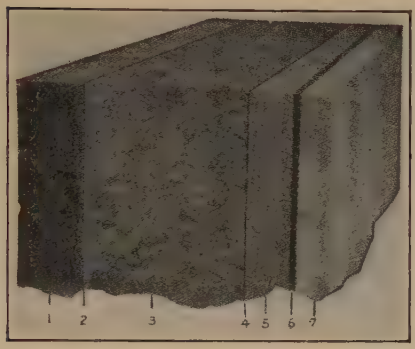


FIG. 91.—Showing construction of refrigerators.

1. Exterior case of quartered-sawed oak.
2. Insulating sheathing.
3. Thickness of lumber.
4. Insulating sheathing.
5. Mineral wool.
6. Insulating sheathing.
7. Thickness of lumber.
8. Insulating felt. (This acts as a cushion for the opal glass lining, insuring it against breakage.)
9. Interior lining of pure white opal glass $\frac{7}{16}$ in. (practically $\frac{1}{2}$ in.) thick.

FIG. 92.—Location of food in a refrigerator.

outside temperatures of 22° F. It is evident that the first refrigerator had very poor insulation and was unsatisfactory.

In good refrigerators the difference between the inside and outside temperatures should be around 22° F. and, based on the average values for a large number of satisfactory refrigerators, the ice consumption for an *empty* refrigerator in pounds per hour to lower the temperature 1° F. per cubic foot of food chamber should be about 0.0056 lb. In a refrigerator having a food chamber of 6 cu. ft. and maintaining a temperature of 22° below the outside temperature, this would mean an ice consumption per day of about 16 lb. Since 144 B.t.u. are required to melt 1 lb. of ice, then $144 \times 16 = (2{,}304$ B.t.u.) of heat have passed through the walls of the refrigerator during the day. But if we assume that the water from the melted ice left the refrigerator at 40° F., it was warmed from 32 to 40°, or 8×16 (= 128 B.t.u.) more heat units came into the refrigerator, making the total influx of heat 2,432 B.t.u. To absorb 2,432 B.t.u. required 16 lb. of ice and at $0.50 per hundredweight, the cost was $0.08. To produce the same amount of heat from gas with a burner 50 per cent efficient, the gas costing $1 per 1,000 cu. ft., would cost $0.008. Absorbing heat in the refrigerator is therefore ten times more costly than producing it from gas. The latter can be controlled, but the waste of the ice goes on constantly, hence the importance of a well-insulated refrigerator.

Many manufacturers make much of the "dry cold air" in their refrigerators. But the ability of air to hold moisture without reaching the saturation point decreases as the temperature decreases. It is the saturation or condensation point and not the absolute humidity that indicates a dangerous condition. If in a given refrigerator the humidity shows a value very near the saturation point for the temperature maintained, then condensation may take place and give "wet air." In tests of several refrigerators an exposed cup of salt placed in the food chamber showed no increase in weight at the end of 48 hr.

From a theoretical standpoint "top icing" as compared with side icing ought to show a slightly greater fall in temperature

as the cold air then falls directly and quickly, while in the side icing a circulation of air must be established. The advantage, however, is not very great.

The consumption of ice in any refrigerator is increased if the refrigerator is placed in strong drafts or in a damp cellar. A warm room where the air is not moving much is better than either of the other positions and a place where the air is dry, cool and relatively at rest, is the best position. The reason for these differences will be readily seen by considering the convection and conduction effects.

Since the temperature of the food chamber is not the same throughout, those foods demanding the lowest temperature should be placed in the coldest part of the chamber. Figure 92 indicates a suggestive arrangement to accomplish this.

Study Exercises

1. Why is the bottom of a tin can filled with air melted off when placed on a stove, but not if filled with water?
2. Will a dish of hot food cool more quickly when standing out of doors or when placed in a pan of cool water? Why?
3. Some ice boxes provide a common shelf for the ice and the food. Is this an efficient scheme?
4. Why do birds ruffle up their feathers on cold days?
5. Why does touching the bread pan in the oven give a more severe burn than touching the bread?
6. Why should the young brother's tongue freeze almost instantly to the frost-covered axe blade but not to the handle?
7. Where, in the refrigerator, is it best to place the odorous food? Why?
8. Can a room be aired more quickly in winter or in summer by opening the windows? Why?
9. A gentleman who was going to attend a lecture on a summer afternoon when the temperature was around 100° in the shade said he intended to wear an overcoat. Was he altogether wrong?
10. If air is such a poor conductor, why not build a fireless cooker box with double walls filled with air?
11. Why blow on your hands to warm them in winter and fan yourself to keep cool in summer?
12. If a door is partly open between a cold and a warm room, in what direction will a candle flame be blown if placed at the bottom of the door? If at the top? Explain.

13. In one fireless cooker 8 lb. of water at 212° F. cooled to 172° F. in 2 hr. In another, 8 lb. of water at 212° cooled to 142° F. in 3 hr. Which is the better heat retainer?

14. In one 4-qt. pan, 5 lb. of water were warmed from 60 to 200° F. in 30 min. In another similar pan of different material the same amount of water was warmed from 60 to 190° in 25 min. on the same fire. Which pan is the better conductor?

15. A window is 120 cm. by 200 cm. and is 0.4 cm. thick. If the temperature in the room is 20° C. and that of the external air 0° C., find the loss of heat in 10 hr.

16. Why will a hot coal from the fire quickly become dead if taken up on the bare shovel, but glow for some time if ashes are under it on the shovel?

17. Explain the effect of having the back of a fireplace highly polished. Will the shape of the back have any effect on the amount of radiation sent out?

18. Why will mist clear from gold rimmed glasses more quickly than from the rimless glasses?

168. Heat Losses in a Residence. 1. *Conduction and Radiation.*—Heat is conducted through the walls, windows and other exposed surfaces and then radiated. This loss varies with the difference in temperature between the inside and outside air, with the area exposed, with the kind of material, its thickness and method of construction, and with the exposure.

Some idea of these various losses may be obtained from the tables which give the loss in B.t.u. per hour per square foot of exposed surface per degree difference in temperature. The values given are of necessity only approximate.

	British Thermal Unit
Brick wall, 8 in. thick	0.4
Windows, single glass	1.0
Wooden door, 2 in. thick	0.36
Floor	0.40
Walls of average wooden building	0.25

The effect of exposure is shown by the practice of increasing the values above from 10 to 20 per cent for rooms with a north, northeast, or northwest exposure.

2. *Convection.*—The warm inside air is constantly passing out through the various openings to the outside, carrying its

heat with it. This loss of heat due to convection is hard to determine, but is usually taken as being 10 to 20 per cent of the total heat loss, depending on the construction of the house and the location of the rooms with respect to winds and sun. The air in halls is assumed to be changed three times per hour, that of rooms on the first floor two times per hour, and that of rooms on the second floor once per hour as a result of convection.

3. *Ventilation.*—If the amount of fresh air coming into a room to replace the loss due to leakage is not sufficient for good ventilation (frequently it is not) then heat must be supplied to the cold fresh air which is sent into the room for ventilation. Since, in having its temperature raised 1° F., 55 cu. ft. of air will absorb approximately the same amount of heat at 1 lb. of water, the heat loss can be computed when the volume of cold air admitted per hour and the temperature difference are known.

169. Heat Loss Computed.—Let us assume as a type room, a sitting room 18 by 14 by 10 ft., south and west exposure. The wall and ceiling surface W will be 598 sq. ft., the window surface G is 50 sq. ft., the volume C of the room is 2,520 cu. ft., the air change per hour due to leakage only, n, is twice the volume, and the difference in temperature t between room and the outside is 70° F. Carpenter has shown that, taking the heat loss of an average wooden residence building as 0.25 B.t.u. per square foot, the following equation will give the heat loss approximately.

$$\text{Heat loss, B.t.u. per hour} = (G + 0.25W + 0.02nC)t.$$

For the data above:

$$\text{Heat loss} = [(50 + 0.25(598 + 252 \times 0.4) + 0.02 \times 2 \times 2{,}520]t.$$

$$= 22{,}785 \text{ B.t.u.}$$

The quantity, 252×0.4, represents the floor area reduced to equivalent wall area and included under W.

In recent years a number of heat insulating materials have been produced, whose cost is moderate, and the use of these materials reduces the heat loss.

Study Exercises

1. Compute the heat losses in your home living room using the method just discussed.

2. If an upstairs room 12 by 16 by 9 is to be used 4 hours an evening with an outdoor temperature of 10° F., assume conditions and find the B.t.u.'s per hour to be supplied.

Some Suggested Laboratory Exercises

1. Study of the convection in a hot water system. Glass.

2. Determination of the conductivity of wool, cotton, and silk.

3. Study of the convection and radiation factors in thermos bottles. One bottle unsilvered with a vacuum, one bottle silvered but with no vacuum.

4. Study of iron hot-water radiators with different surfaces; dull, polished, nickeled, lamp blacked, painted.

5. Comparative study of two refrigerators.

REVIEW SUMMARY

Three ways of distributing heat, conduction, convection, and radiation.

Convection, the distribution of heat by the bodily movement of the heat medium, liquids, or gases.

Factors affecting convection: difference in temperature between the hot and cold parts of the medium, the specific heat of the medium, the coefficient of volume expansion of the medium, the viscosity, the size, and other conditions of the channels through which the medium moves.

Conduction, the transfer of heat from particle to particle. Greatest in solids, least in gases. Amount of heat conducted $= \frac{kA(t - t_1)T}{L}$.

Conductivity and temperature sense.

Air, a poor conductor.

Radiation—energy sent out from all bodies as a wave motion in the ether and when absorbed by bodies, is transformed into heat.

Properties of heat radiation:

1. Transmitted through a vacuum.
2. Reflected like light.
3. Good radiation absorbers are good emitters of heat radiations.
4. Amount of heat sent to a given body by radiation varies inversely as the square of the distance of the body from the radiating source. Newton's law of cooling: Rate of cooling is proportional to excess of temperature between the body and the surrounding medium. Also the amount of cooling depends upon the nature of the body, the condition of its surface, and the temperature of its surface. Thermos bottle, fireless cooker, gas stove insulation, refrigerators. Practical approximate method of computing the heat loss of a home.

CHAPTER XVII

HEATING SYSTEMS

170. Study of Heating Systems. (*a*) *The Fireplace.*—The character of the heat given out from a fireplace is very different from the hot-air or radiator systems of heating. By far the greater part of its heat is sent out by direct radiation from the glowing coals. A very little comes into the room from the heated brick work of the fireplace by means of convection. The radiant heat given out from the hot-water or steam radiator consists of relatively long ether waves and forms but a small part of the total heat received which is largely due to convection of the air. But the radiation from the fireplace consists of much shorter heat and light waves. These shorter or higher frequency waves fall on people or objects in the room and are transformed into heat, and those not falling directly in this way reach the walls where they are partly absorbed and partly reflected again (see Fig. 72).

No reliable data have as yet been obtained on the proportion of heat sent into the room from a fireplace. An estimate has been made by Barker as follows: Assume that 3,500 to 4,000 B.t.u. are radiated into a room from each square foot of the fuel surface. Then, if it takes 3.5 lb. of coal per square foot of fire surface per hour to maintain the fire and the heat combustion of the coal is 13,000 B.t.u. per pound, the fireplace radiates about 10 per cent of the total heat into the room.

In spite of its very low efficiency as a heater, the fireplace has at least two advantages that tend to offset its high cost of operation. First, in the better ventilation of the room. It is a conservative estimate to say that the ventilation of a room with an open fire is 250 per cent better than when the fire is not lighted. Second, in its subjective effects. A glowing fire fills a room with a feeling of comfort, warmth and cheerful-

ness that no other system can produce. Of course, a certain temperature must be had in a room, but what part of the feeling of comfort and warmth should be credited to the actual temperature of the room and what part to the effects of the open fire? One of the factors which enters into the question will be discussed. It is generally agreed that a room warmed by an open fire is more comfortable to the occupant than if heated by radiators, hot water or steam. Let the air in a room be at 68°, giving its heat to the walls and windows, both of which are colder than the air in the room. With a temperature of 36° outside, we may assume the temperature of the walls to be about 56° and that of the window glass about 49°. The result follows that the occupants are radiating heat to the walls which tends to produce discomfort. Now let the room be heated by an open fire; the walls are now warmer than the air in the room because the radiant heat passes through the air with little absorption. The air coming into the room is colder than the walls and receives its heat from them. The occupants are breathing and surrounded by air cooler than the walls and are not losing heat as rapidly by radiation to the walls. This seemingly tends to produce the feeling of comfort and warmth.

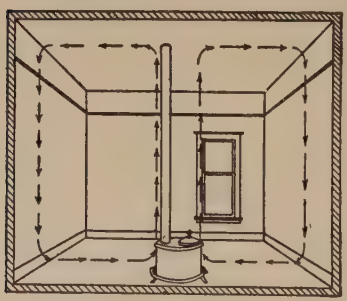


Fig. 93.—Stove heating.

(*b*) *Stoves.*—By enclosing the process of combustion, the method of heating is radically changed. The outside surface becoming hot by conduction sends out long wave-length vibrations and, heating the air, sets up convection currents. The stove is much more economical of fuel than the open fire, sometimes giving an efficiency of 70 per cent, although 30 to 40 per cent is more common. The temperature of the surface is usually around 350° F., but occasionally runs up to 800 or 1000° F. Stove heating, as used, is a cheap form of heating, but has the disadvantage of producing frequently a feeling of oppression.

(*c*) *Hot-air Heating.*—The hot-air furnace is a very common type of heater for residences. Its chief advantages are the low cost of installation, the combination of heating and ventilation, the quickness and ease with which the system responds to light or heavy service with sudden changes in the outside temperature. Some of the disadvantages of the system are: the cost of operation, the leakage of fuel gases into the air supply, and the difficulty of heating the windward side of the house. The first objection can be largely controlled by the type of furnace and the reheating of at least a part of the

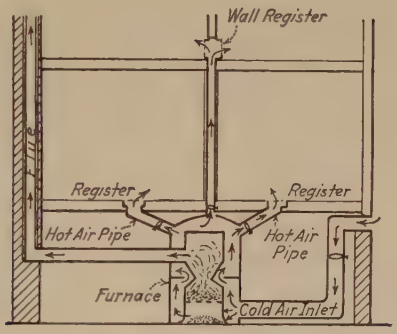


FIG. 94.—Hot-air furnace.

used air. The leakage of gas is greatly reduced by proper firing. The chief objection, the difficulty of heating certain rooms on the windward side of the house, can be largely overcome by having two outside air ducts, one on either side of the house, arranged with dampers for closing either one or both, and by taking some of the air supply from the rooms.

The illustration shows clearly the essential parts of a hot-air system.

171. Heat Required under Different Conditions.—Consider the sitting room used in **Art. 169** which was 18 by 14 by 10 ft. when heated by a hot-air furnace on a day with the temperature at zero.

(*a*) When all the air is recirculated, no direct means of bringing in fresh outside air:

The only heat losses are those computed in **Art. 169** and are taken to be 22,000 B.t.u. per hour.

(*b*) When only enough fresh air is brought into the room to furnish good ventilation for three persons:

If we assume each person requires 1,800 cu. ft. of fresh air per hour, then 5,400 cu. ft. of outside air at 0° F. must go through the furnace, be heated to 70°, pass into the room and finally go to the outside.

The total heat loss will now be $22{,}000 \times (5{,}400 \times 0.08 \times 0.24 \times 70) = 29{,}257$ B.t.u. or approximately 33 per cent more heat must be furnished by the furnace than was required in (*a*).

(*c*) When all the air is exhausted:

Assume the air from the furnace enters the room at 130° F. and is exhausted at 70° F. Then each cubic foot of air entering the room will bring in $60 \times 0.08 \times 0.24 = 1.15$ B.t.u. To replace the 22,000 B.t.u. lost per hour from the room will require $\frac{22{,}000}{1.15} = 19{,}130$ cu. ft. of air to be heated from 0 to 130° F.

The furnace then must deliver to the room $19{,}130 \times 130 \times 0.08 \times 0.24 = 47{,}634$ B.t.u. each hour. This is over 100 per cent more heat to be furnished than in (*a*) and 62 per cent more than in (*b*).

Since few houses have a natural leakage of air sufficient for good ventilation, the second method (*b*) is, in general, the better one to use.

172. The Furnace.—A furnace having a somewhat larger air heating capacity than the size of the house actually requires has usually been found to be more economical of coal. It will permit larger volumes of air moving at slower velocities, thus making unnecessary the forcing of the fire, which is wasteful. The modern hot air furnace may deliver as much as 75 per cent of the heat units in the coal to the rooms, though its efficiency is usually somewhat less, 40 to 50 per cent.

173. Hot-air and Hot-water or Steam-radiator Air Circulation.—The figures show some typical air circulations in a room with the two types of heating systems under different conditions. Can you see any reason why in our homes we do not

use, for hot air, the system shown which gives the best circulation? Does the radiator system in your home provide a cold air inlet at the radiator?

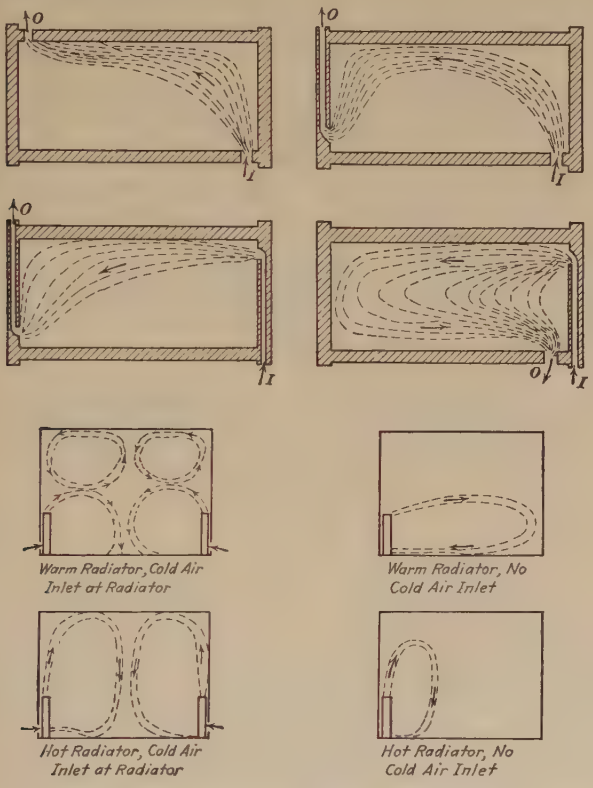


FIG. 95.—Air circulation under different conditions of heating.

174. Rough Rules for Hot-air Systems.—Professor Allen gives the following empirical rules:

1. The volume of the house divided by 50 equals the square feet of heating surface in the furnace radiator.

2. The volume of the house divided by 20 equals the number of square inches of grate area in the furnace.

3. Divide the cubic-foot volume of a room by 20 and the square root of the quotient will be the diameter of the furnace

pipe to the first-floor rooms. For second-floor rooms use 25 in place of 20 and proceed as before.

The volume of our type room was 2,520 cu. ft. The diameter of the furnace pipe bringing heat to it should be, therefore,

$$\sqrt{2520 \div 20} = 11.2$$

175. Character of the Air Circulation in a Room.—The position of the heat register with respect to the vent or outlet register will determine very largely the distribution of the heated air. The figures show clearly the effect of different locations and we can readily understand why the best location is not used in house heating (see Fig. 95).

176. Hot-water and Steam Heating. *Comparisons of the Systems.*—The hot-water and the steam systems both show increase in the cost of installation compared with the hot-air

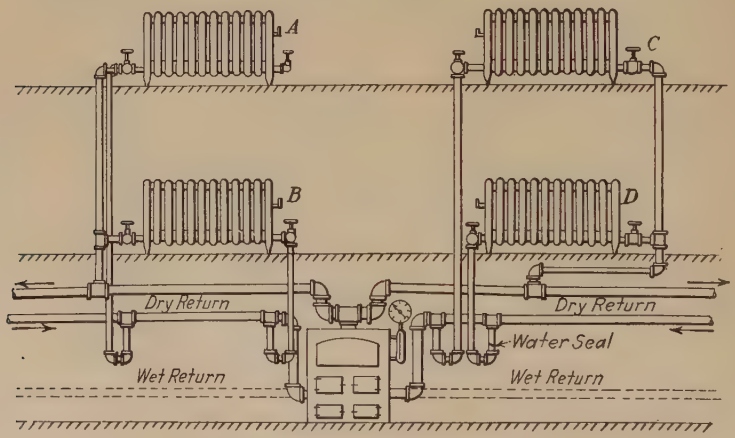


FIG. 96.—Steam-heating system.

system, and generally the hot-water system costs more than the steam system. Both systems are more complicated, using a less flexible heating medium and requiring a return path for the medium. The radiators take up floor space, while registers do not to the same extent. They do not respond as quickly to sudden demands for less or more heat, although they tend to give a more uniform distribution throughout the day. They

overcome the effect of wind and exposure on certain rooms, but usually, as found in the home, do not provide any direct means of ventilation. The cost of operation is generally somewhat less than that of the hot-air systems.

While the difference is not large, the efficiency of the steam boiler is usually considered to be lower than that of the hot-water boiler. The demand for a lower temperature on warm days is met in the steam system by shutting off the radiator, but in the hot-water system the reducing of fuel consumption by the furnace lowers the temperature of the radiator. If this

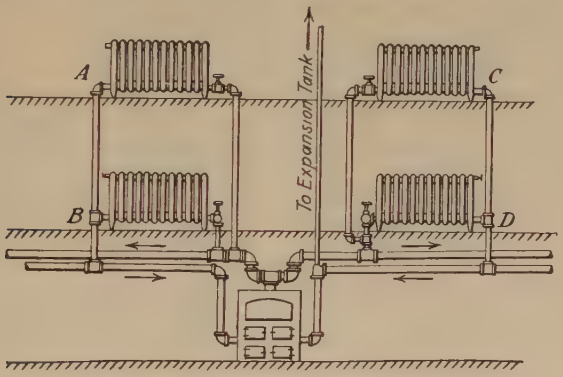


FIG. 97.—Hot-water heating system.

method is used for the steam system, some few radiators near the boiler will generally take all the heat, giving those rooms too much heat while the other radiators will be cold. Steam systems respond more quickly to sudden demands for temperature changes than the hot-water system. When once the hot-water radiators have reached any temperature, the high heat capacity of the large amount of water makes the response very slow to a demand for a change. Another objection to the steam system is found in the disagreeable odor always accompanying any radiator above 150° F. It is absent, at least for most persons, in the hot-water system.

The efficiency of any heating system, from the heat distribution standpoint, is the ratio of the heat units delivered to the rooms to the heat units in the fuel consumed. Any given

installation may vary widely from the value to be given, but perhaps a fair value is from 40 to 70 per cent.

177. The Essential Parts of Steam and Hot-water Systems. These systems have three chief parts: the furnace or heat generator, the connecting pipe lines for the water or steam, and the radiators or heat distributors. The hot-water furnace must always be below the lowest point in the circuit, as the water movement is due entirely to convection. Heat distributors may, on the other hand, be placed below the steam furnace, since the movement of the steam is due to a positive and greater force than that of convection. The steam radiator placed below the generator will need, however, to have its condensation water taken care of in some way.

178. Radiator Surface Paints.—Allen has made a careful series of tests on the effect of painting radiator surfaces. As its radiating ability is chiefly affected, the number of coats of paint produces little effect, the character of the last coat being the one that makes the difference. The table given is from Allen's work.

Kind of Surface	Heat Transmission, Relative
Bare iron surface	1
Copper bronze	0.76
Aluminum bronze	0.752
Snow white enamel	1.01
No luster green enamel	0.956
Terra-cotta enamel	1.038
Maroon glass Japan	0.997
White-lead paint	0.987
White-zinc paint	1.01

179. Amount of Heat from Radiators.—Experiments indicate that the average cast-iron radiators will give off heat at the rate of 1.7 B.t.u. per hour per square foot of surface per degree difference between the temperature of the surrounding air and the average temperature of the hot water. In general, we may assume the water to enter the radiator at 180° F. and leave it at 160° F., making the average temperature of the hot water 170° F. For the type room used in the hot-air system

with a temperature of 70° F., the degree of difference in the rule above is (170 − 70) = 100°. Therefore, the radiator will give off (1.7 × 100) = 170 B.t.u. per square foot per hour. In a steam radiator working under a pressure of 2 to 5 lb., the temperature is assumed as 220° F., so such a radiator will give off per square foot per hour (220 − 70)1.7 = 225 B.t.u. In our type room where the heat loss was taken as 22,000 B.t.u., the number of square feet of hot water radiator surface necessary will evidently be 22,000 ÷ 170 = 130 sq. ft., while for the

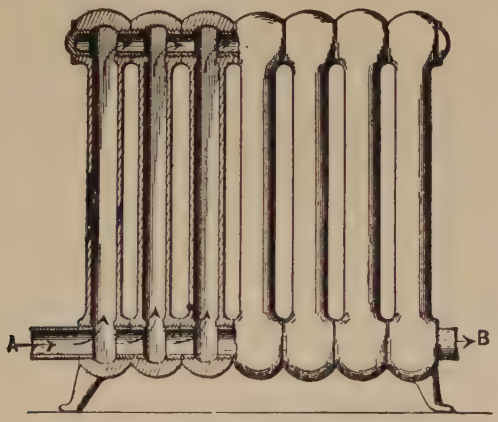


FIG. 98.—Section view of hot water radiator.

steam it will be 22,000 ÷ 255 = 86 sq. ft., or hot water radiators should have approximately 50 per cent more radiating surface.

180. Water Hammer and Air in Radiator.—The term "water hammer" is applied to a hard concussion which frequently occurs in steam pipes or radiators. It is caused by the accumulation of water in the pipes or radiators which condenses some of the steam, producing a vacuum which is immediately filled by a rush of steam and water. The impact against the walls is severe, not infrequently producing damage and always making unnecessary noise. Proper piping, so arranged as to carry off at once the condensed water from the pipes or radiator, will prevent this. Also, if the radiator is

cold or full of water, admitting the steam very slowly will reduce the hammer.

Since air accumulates in both kinds of radiators, air valves for its escape must be provided. Air being heavier than steam, although it will mix with it to some extent, the valves on steam radiators are not placed at the top of the radiator but part way down, while in the hot-water radiator, the valves are placed at the top.

REVIEW SUMMARY

Fireplace, perhaps, 10 per cent efficient. Gives good ventilation, produces feeling of warmth, cheerfulness, comfort.

Stoves, more efficient, 70 to 40 per cent, cheap form of heating.

Hot-air furnaces, low cost of installation, good ventilation, responds quickly to varying demands for heat. Cost of operation, gas leakage, difficulty of heating certain rooms are its disadvantages.

Three ways of using hot-air furnace. First, when all air is recirculated, most economical; second, part of air recirculated some outside air going through the furnace—better ventilation, somewhat more coal used; third, all the air brought in from the outside—most expensive way, best ventilation.

Hot-water and steam systems: higher cost of installation, system more complicated, take up more space in a room, do not respond quickly, cost of operation less, provide no ventilation.

Effect of different paints on heat liberated, aluminum paint poorest—for most paints used not much difference.

Radiators give off on average about 1.7 B.t.u. per square foot of surface for each degree Fahrenheit difference in temperature between hot water radiator and the air in the room, or under average working conditions, about 170 B.t.u. per hour per square foot. Steam radiators under average working conditions will give out about 255 B.t.u. per hour per square foot.

CHAPTER XVIII

HUMIDITY AND VENTILATION

181. Role Played by Humidity.—In all problems concerning the house heating, sanitation, and hygiene, the importance of humidity is being more fully recognized. The dry air in the home in the winter months shows its effect on woodwork and furniture.

Our bodily comfort is as closely connected with the humidity conditions as with the temperature conditions. Indeed, improper humidity plays an important part in determining our health.

182. Humidity Defined.—The condition of the air as regards the amount of water vapor in it, is known as its humidity. Humidity is expressed in two ways, the absolute and relative humidity. By *absolute humidity* is meant the number of grams or pounds of water that are present at a particular time in each cubic meter or cubic foot of the air. By *relative humidity* is meant the ratio of the amount of water in a given volume of the air to the amount of water that would be in the *same* volume of air if it were saturated at the same temperature.

The amount of water in 1 cu. ft. of air saturated at 65° F. is 0.000098 lb. or 6.87 gr. At 70° F. for saturation, the amount is 8 gr. The absolute humidity is then at the two temperatures 6.87 gr. and 8 gr., respectively, per cubic foot.

If air, saturated at 65°, is heated to 70° F., it does not lose water as is frequently thought, but the air at 70° holding 6.87 gr. is not saturated, since it can hold 8 gr. Its relative humidity is 6.87/8, or 86 per cent.

The hottest and driest place in the United States has a relative humidity of about 16 per cent. A heated living room may show a relative humidity of 20 per cent, only a little above that of Death Valley, the driest place in the United States.

The "balmy air of June" is due to a combination of humidity and temperature. The same temperature may exist at other seasons, but it is not usually found with the same humidity.

FIG. 99.—The sling hygrometer.

183. Humidity Measured. Hygrometry. For most practical purposes, relative humidity is determined, and two methods of finding it will be described.

(*a*) *Wet- and Dry-bulb Hygrometer.*—Two similar thermometers are mounted side by side on a frame to which a handle is pivoted, permitting the rotation of the thermometers. One of the thermometers is covered with a muslin bag which is wet before using the instrument.

The hygrometer is rotated with a velocity of about 10 ft. per second for 3 or 4 min. The temperature of each thermometer is read and the dryness of the air is indicated by the lowering of the temperature on the wet-bulb thermometer due to evaporation.

From the temperature readings of the two thermometers, the relative humidity may be found with the aid of prepared tables. A partial table is given below:

Dry-bulb reading	Wet-bulb reading	Relative humidity, percentage
65°	61°	80
	59°	70
	55°	52
68°	57°	50
	56°	47
	55°	43
	53°	35
	49°	21

(*b*) *The Hygrodeik.*—In Fig. 100 is shown an instrument for determining relative humidity without the use of tables or the necessity of swinging the thermometers. The figure clearly shows the wet- and dry-bulb thermometers and the cistern which holds the water for the wet-bulb thermometer. Between the thermometers is a special chart from which the humidity may be obtained without the use of a table.

To use the hygrodeik, the index arm is moved to the left and the pointer adjusted to the temperature scale reading of the wet-bulb thermometer. The index arm is then moved to

FIG. 100.—The hygrodeik.

the right until the pointer touches the downward curved line which starts from the temperature reading on the dry-bulb thermometer. The lower end of the index arm points to the relative humidity as given by a scale at the bottom of the chart.

Stationary instruments are not as accurate as the moving type first described, but are sufficiently reliable for all humidity determinations in the home, in school rooms, or in other public buildings.

Other and cheaper hygrometers, usually depending for their actions on the absorptive property of catgut or hair for moisture, are in use, but except for very limited ranges of humidity they are unreliable. They need to be frequently checked and

compared with some standard instrument if quantitative readings are to be obtained.

184. Humidity of the Air in the Home.—The relation between our feeling of comfort and the humidity is a very real one. The skin offers a large surface for evaporation, and as heat is taken from the surface of the body during evaporation the skin is at a lower temperature than the body. The amount of this difference in temperature increases with the dryness of the air, or with an increasing rate of evaporation. If cold air of a given humidity is warmed the evaporation from the skin is more rapid since the relative humidity of the warm air is less. The result is that we may feel cooler at the higher temperature. Too low relative humidity in a room permits rapid evaporation from the skin, producing a sense of cold in a warm room. On the other hand a moderately warm humid room gives the effect of a higher temperature since the evaporation from the skin is slowed up. The "balmy air of June" is a familiar example of the combined effect of humidity and temperature. The excessive dryness usually found in our homes in the winter, producing a dry skin and tending to dry the membranes of the nose and throat, helps to produce many of the ailments of the throat, nose, and lungs. The discomfort may also produce nervousness and restlessness. The New York State Commission on Ventilation reports do not present enough data on these points and so propose to subject the entire question of the proper humidity in living rooms to a series of careful tests. For the present we may assume that the humidity in our homes is too low and that it ought to be about 50 per cent.

In the heating systems discussed in the preceding chapter some method of adding moisture to the warmed air is absolutely necessary. While the hot-air furnace is usually considered as especially bad in producing dry air, it is, as a matter of fact, better than the hot-water or steam systems as ordinarily used.

The hot-air furnace is provided with a water pan at the side of the fire box. But it does not evaporate enough water to produce the necessary humidity.

Consider a house whose four living rooms have a volume of 6,372 cu. ft. Let it be assumed that the air is changed by ventilation 18 times during the 24-hr. Then there will enter the house 6,372 × 18 = 114,696 cu. ft. of air during the 24 hrs. If the air outside is at 36° F. and a relative humidity of 85 per cent it will have 2.3 gr. of water for each cubic foot. To each cubic foot of entering air there must be added 1.58 gr. of water if the relative humidity of the house is to be 50 per cent, or 114,696 × 1.58 = 181,219.69 gr. of water. Reducing this to pounds, 181,219.69 ÷ 7,000 = 25.8 lb., or over 3 gal. of water per day.

The following table of tests, reported by Hodgdon,[1] is at least interesting:

Temperature	75 Per Cent Relative Humidity Bodily Feeling
55° F.	Very cold
65° F.	Chilly
75° F.	Comfortable
85° F.	Too warm
95° F.	Very hot
	50 Per Cent Relative Humidity
35° F.	Very cold
50° F.	Chilly
65° F.	Comfortable
75° F.	Warm
85° F.	Too warm
95° F.	Very hot
	30 Per Cent Relative Humidity
55° F.	Very cold
65° F.	Chilly
75° F.	Comfortable
85° F.	Warm
95° F.	Too warm
105° F.	Very hot

A home with a proper humidity is not only more comfortable and healthy, but requires less coal to yield the same degree of comfort.

[1] Hodgdon, Hines, Hayden and Eldredge, "Elementary General Science."

VENTILATION

185. Pure Air versus Pure Food.—The average person inhales 2,600 gal. of air in 24 hr., or approximately 34 lb. His food, including solids and liquids, will amount to about 5.5 lb. or approximately one-sixth the weight of air used. We give very careful attention to the purity of the food, it must not be adulterated, but the air we breathe in our living rooms is not usually so carefully selected.

186. Air in the Living Room.—Up to a very recent date it was assumed that bad air was bad because of lack of oxygen, or excess of carbon dioxide, or to the presence of some poison of human origin. The amount of carbon dioxide present was taken as the standard of badness of the air and more than 6 parts of it in 10,000 parts was considered bad.

The recent careful work on ventilation done by the New York State Commission on Ventilation seemingly shows that air is bad, not because of its carbon-dioxide content, but because of high temperature, lack of cooling air currents, and high humidity. The feeling of comfort that comes from simply stirring up the bad air in a room by an electric fan is very marked.

Their first report reaches the following conclusion:

> The thermometer is the first essential in estimating the success of ventilation. Temperature standards must come into general use and a rise above 70° must be recognized as a sign that discomfort is being produced and vitality lowered and efficiency decreased. The carbon-dioxide standard is still of value, however, as ordinarily a measure of the air change which is required to carry off both heat and odors; and the mechanical standard of 30 cu. ft. per minute per capita as the amount necessary to supply in some way, if an occupied room is to remain cool and fresh, is still of general application.

Some Suggested Laboratory Exercises

1. Study of the humidity conditions in the laboratory and the home. Three-day tests.
2. Study of the CO_2 content of living rooms and the laboratory. Wolpert Air Tester.

REVIEW SUMMARY

Humidity of air important for health and comfort.

Humidity is the term used to denote the water-vapor content of the air.

Absolute humidity is the amount of water vapor present per unit volume of air.

Relative humidity is the amount present in the air at any temperature compared with the amount of water vapor the air would have if it were saturated at that temperature.

Two instruments for measuring relative humidity, sling hygrometer and the hygrodeik.

Humidity of air in living room should be about 50 per cent.

Importance of ventilation. About 30 cu. ft. of air per minute per person is a standard for good ventilation.

LIGHT

CHAPTER XIX

RECTILINEAR PROPAGATION AND PHOTOMETRY

187. Light Defined.—Light is the result of vibrations of the ether which produce the sensation of sight. The word "light" has two distinct meanings: One in which the sensations coming to the eye are of chief concern, the subjective aspect, and the other in which the physical causes of the sensation are studied, the objective side. In our study we shall consider both aspects.

188. Infra-red and Ultra-violet Light.—As we shall see later, the radiations which affect the eye and are called light radiations, are composed of a rather limited range of frequencies or wave lengths. If the wave lengths are longer than about 0.0007 mm. the radiations are spoken of as *infra-red* light and if the wave lengths are shorter than about 0.00035, these radiations are called *ultra-violet* light. These radiations do not produce the sensation of sight although they each produce characteristic effects.

Some of the effects of infra-red light have been discussed under the term "radiant heat."

Ultra-violet light radiations are comprised between the wave lengths 0.00035 to about 0.00015 mm. Ordinary glass does not transmit radiations of wave length shorter than about 0.00033 mm. Quartz or some special glasses now made are necessary for the transmission of this light.

These radiations produce chemical and physiological reactions. The range of wave lengths 0.000315 mm. to 0.000290 has been found to promote health and to cure certain diseases and these wave lengths are popularly known as "vital rays." There are, however, dangers attendant on their indiscriminate use, and so they should be used only with the advice of a physician.

189. Source of Light.—A moment's reflection will convince one that the chief sources of light and heat are the same. As the sun is the great source of heat so it is for light, and our artificial sources come from the burning of wax, fats, oils and gas; or when produced by electrical means, as in the incandescent and arc lamps, come from the high temperature of these substances.

190. Rectilinear Propagation of Light.—We are all familiar with shadows, and some may have noticed that their contour is determined by drawing *straight* lines from the source of light past the edges of the object which casts the shadow.

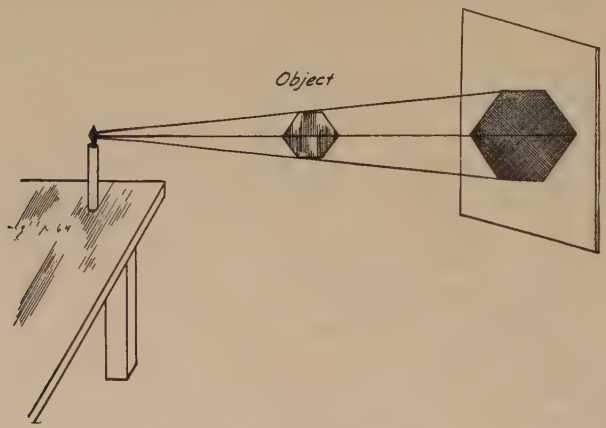


FIG. 101.—Shadows.

Shadows, then, are the result of the rectilinear propagation of light. If a source of light or an illuminated object is placed before an opaque screen containing a small opening, an image of the source or object can be obtained on another screen. Light from every part of the object passes *in straight lines* through the opening, forming an inverted image on the second screen.

The impossibility of light, under ordinary conditions, turning a corner, the disappearance of a lighted candle when a small opaque object is held between the eye and the candle, the straight path of light coming through a hole or crack in a

curtain, as shown by the illuminated dust particles, all result from the rectilinear propagation of light. The sighting along a rifle and the threading of a needle by holding it between the light and the eye are also examples.

The terms, "beam of light" and "ray of light" may have come from observing the light streaming through a hole or a small crack into a dark room. The words are now used in place of a "light wave," and beams and rays have no real existence. They refer simply to the *direction* in which light is propagated.

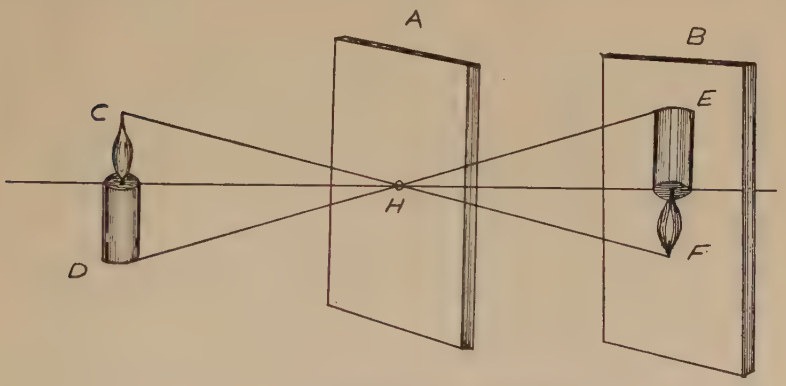


FIG. 102.—Image from a small aperture.

191. Intensity of a Light Source.—As light is a wave motion in the ether, if we consider a disturbance which starts at S, after an interval of time it will be distributed over a sphere of radius r and area a, r being the distance the light has traveled in the time interval. The entire surface a has received the light energy from S. Now, after a second time interval, the disturbance is on a sphere of radius R and area A. Since each spherical surface has in turn received all the light energy from S and these surfaces have areas varying as $r^2 : R^2$, the intensity of the light on unit area of each sphere must vary so that

$$I_a : I_A :: A : a$$

But

$$a : A :: r^2 : R^2$$

Hence

$$I_a : I_A :: R^2 : r^2$$

The intensity of light varies, then, inversely as the square of the distance from the source. The fact is also clearly shown from the figure below.

If a 15-watt tungsten light in a table lamp will produce a certain intensity on the printed page when 18 in. from it, the same light in a ceiling fixture 72 in. above the book will produce but one-sixteenth as much illumination.

FIG. 103.—Intensity and distance.

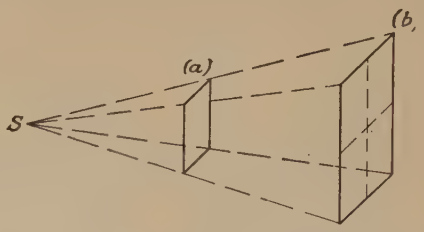


FIG. 104.—Intensity and area.

(The screen b is twice the distance from the source, S of a. The area of b is four times that of a.)

192. Luminous Intensity.—The luminous intensity of a beam of light should be measured by the intensity of the light sensation it can produce. It is then physiological rather than physical in character. But a given beam of light entering the eyes of different individuals produces different effects. Our sensations of light intensities are no more quantitative than are our sensations of sound intensity or of temperature. We measure the luminous intensity of a source of light by finding the ratio of the luminous intensities of two light sources, one of known intensity, by a device called a "photometer."

The photometer is placed between the standard intensity source and the unknown intensity source. It is moved along the straight line connecting the two until the eye agrees that the illuminations produced by each at the photometer are equal. The eye is a fairly accurate judge of the equality of the two illuminations.

193. Standard of Physical Intensity. Units.—When intensities were first measured, the candle was a common source of light, and so a candle burning under definite conditions was the standard chosen. Later, different forms of liquid-burning lamps were used as standards and at present we have three recognized types: the Hefner lamp, burning amyl acetate, the German standard; the Harcourt lamp burning pentane, the English standard; and the Carcel lamp, burning rape-seed oil, the French standard. In 1909, the United States, France, and England adopted as the standard of intensity the international candle-power unit and defined it as:

0.1 of the Harcourt pentane unit.
0.104 of the Carcel unit.
1.11 of the Hefner unit.

So the intensity of light from a standard Hefner lamp is 0.9 of the international candle power. In practice, a properly selected and calibrated incandescent lamp is used as a working standard for incandescent lamp photometry.

194. The Photometer.—Of the many forms of photometers but one will be described in order to illustrate their use. The Bunsen photometer consists essentially of a screen with an oil spot in the center as shown, the standard lamp, the lamp to be tested placed on opposite sides of the screen, and a device for measuring the distances between the screen and the two lamps. The oil spot appears darker than the paper by reflected light and lighter than the paper by transmitted light. If the spot is viewed from the side of the brighter light, it appears darker than the paper, while viewed from the side of the weaker light, it appears lighter than the paper. When the physical intensities of the two lights are the same the spot disappears, the entire disc looking uniformly illuminated. The condition is found by varying the distance of the screen from the lamps. *The intensities of the two sources are then directly as the squares of the distances between the screen and the respective lamps.* It will be noticed that while the intensity of light from a single source varies *inversely* as the square of the distance, the *relative* intensities of two sources vary *directly*

as the squares of the respective distances from the screen, *when the illuminations are equal.* This may be seen by considering the figure. The two sources of light, s and S, are the centers of the two spherical waves tangent to each other at the screen, and, as the illumination of the screen was set so

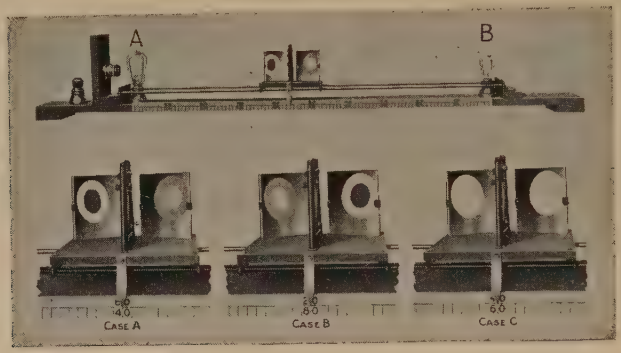


FIG. 105.—Bunsen photometer.

as to give equality of illumination, these spherical waves have equal amounts of energy per unit area on their surfaces. The relative intensities of the sources, s and S, are proportional to the areas of these spherical surfaces; that is, to the square of their radii. Hence, the intensities of the sources

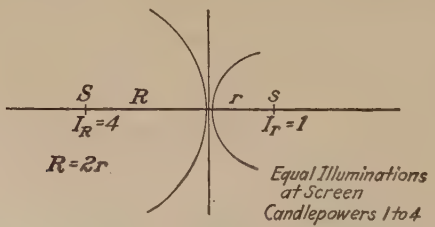


FIG. 106.—Equal illuminations. Candle power 1 to 4.

vary directly as the squares of their respective distances from the screen.

In the figure, source S is twice the distance from the screen that the source s is. If we assume that the intensity of source s is unity, then in order that the source S, twice as far away

and having its light spread over a sphere of four times the area, may have the same amount of light per unit area as the smaller sphere of unit area, its intensity must be four times the intensity of s.

Candle power of s: candle power of $S :: r^2 : R^2$. Law of the photometer.

Study Exercises

1. Two 1-cp. lamps are placed at distances of 2 and 4 ft., respectively from a screen. What is the amount of light per unit area on the screen from each light? *Ans.:* Amounts are as 16 to 4. Law of intensity.

2. A lamp is 8 ft. from one wall and 6 ft. from another wall. What are the relative intensities of the light on each wall?

3. A 1-cp. lamp is 2 ft. from a screen and another lamp is 4 ft. from the screen when the screen is *equally* illuminated by each source. What is the candle power of the other lamp? *Ans.:* 4 cp. Law of the photometer. Compare with question 1.

4. A 16-cp. lamp is 2 ft. from a reading table and a 40-cp. lamp is 4 ft. from another table. What are the relative intensities on the two tables?

5. A Hefner lamp 2 ft. from a photometer screen gives the same illumination as a Harcourt lamp. What is the distance of this lamp from the photometer screen? *Ans.:* 6.6 ft.

6. An 8-cp. lamp is 4 ft. above a desk but the amount of light on the desk is only one-half that desired. What candle power lamp will give the desired amount?

7. A 40-watt tungsten lamp gives 32 cp. and is 5 ft. from a desk. How far away should a 25-watt tungsten lamp of 20 cp. be placed to give the same light on the desk?

195. Unit of Illumination—The Foot-candle.—Light is the cause and illumination is the result or the effect. Candle power is a unit used to measure the intensity of the cause or the source. Illumination is connected with the light received or intercepted by a surface.

If a 1-cp. source is 1 ft. distant from a surface, a point on the surface normal to the source is receiving 1 foot-candle of illumination. If a 2-cp. source is 1 ft. distant from the point on the surface, the illumination would evidently be twice as great or 2 foot-candles. Consider now the illumination produced by a 2 cp. source 2 ft. from the surface. The same amount of light is now falling on a surface four times greater and the amount per unit of area is one-fourth. This comes

directly from the inverse square law of **Art. 191.** The illumination is then ½ foot-candle. The illumination at a point varies *directly* as the candle power of the source and *inversely* as its distance squared from the source, or

$$E, \text{ the illumination in foot-candles} = \frac{\text{candle power of source}}{\text{distance squared}}.$$

196. Brightness.—When light falls on a surface, part of it is reflected, part absorbed, and part transmitted. The emitted, transmitted, or reflected light from an object causes it to appear bright. Differences in brightness or contrast is one of the main effects used by our eyes to distinguish and identify various objects.

If S is the reflecting power of a surface, as given in **Art. 230** or as obtained from **Art. 219,** which receives an illumination of E foot-candles, the brightness of the surface is SE foot-candles. For example, a certain light-tinted wall has a reflection factor of 50 per cent and the illumination received by the wall is 8 foot-candles. The brightness is 4 foot-candles.

If the brightness of a bowl or shade transmitting light is to be found, we may measure by a photometer the candlepower of 1 sq. in. of the bowl, considering it as the source of light. Then the brightness would be expressed in candle power per square inch.

Illustrative Problems

1. A 16-cp. lamp is 3 ft. above a reading desk. What is the illumination on the desk?

The illumination, $E = \text{cp.}/d^2 = 16/9 = 1.7$ foot-candles.

2. What candle power lamp 4 ft. away will give 4 foot-candles on a table?

4 foot-candles $= x/16$, x equals 64 cp.

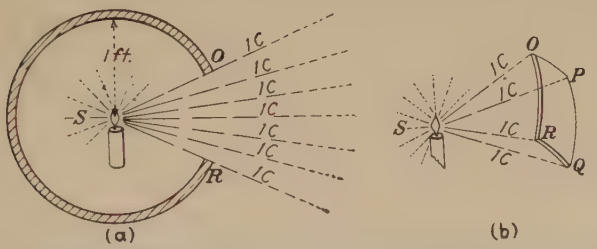
3. If in Problem 2 the book on the desk absorbs 20 per cent of the lights, what is the brightness of the book?

If the book absorbs 20 per cent, then it reflects 80 per cent or S equals 0.8. Then the brightness is $ES = 4 \times 0.8 = 3.2$ ft. c.

4. A piece of white blotting paper reflects 75 per cent of the light received. What candle power lamp at 4 ft. away will be required if the brightness of the paper is to be 3 foot-candles?

If 75 per cent or three-fourths of the light received is reflected then, 4 foot-candles must be the illumination on the paper. Hence, 4 foot-candles $= x/16$, or lamp must be 64 cp.

197. The Lumen.—The candle power of a source does not give complete information about the amount of light being emitted. We need some unit for measuring the total amount of light emitted in all directions from a given source. Assume a source which gives one candle in every direction and place it at the center of a non-reflecting sphere of radius 1 ft. Make an opening in the sphere of 1 sq. ft. area. A certain amount of light will escape; if the opening is twice the area, the amount of light escaping will be twice as great. The candle power of the source has remained *unchanged*, but the amount of light emitted has increased as the area of the opening. It has been



(*a*) Opening *OR* has area of 1 sq. ft. and emits 1 lumen. (*b*) One lumen falls on surface *O P Q R*.

Fig. 107.

agreed that when a 1 cp. source sends light from the sphere through an opening of 1 sq. ft., this amount of light is to be considered *as unit quantity* and is called a "lumen."

We may do away with the sphere and a lumen is then defined as the amount of light from a 1-cp. source falling on a surface 1 ft. square every point of which is 1 ft. distant from the source.

Returning to the sphere again, since it has a surface area of $4\pi r^2$, or, if $r = 1$, of 12.57 sq. ft., then the total amount of light emitted from a source of one candle in all directions, is 12.57 lumens. A source of 16 cp. in all directions would emit 16 $\times$ 12.57 lumens.

In Fig. 107(*b*) the surface *O P Q R* is illuminated at every point to an intensity of 1 foot-candle, and by definition one lumen of light is falling on this area. Therefore, when we know the number of square feet to be lighted and the intensity

of the illumination desired, we can find the amount of light in lumens that must fall on the surface.

Lumens = Foot-candles × area in square feet.

LUMEN TABLE FOR MAZDA LAMPS
Inside frosted

Mazda B vacuum, watts	Initial lumens at 115 volts	Mazda C, gas filled, watts	Initial lumens at 115 volts
10	77		
15	131	50	525
25	240	60	678
40	408	75	923
		100	1,340
		150	2,310
		200	3,280

Illustrative Problems

1. How much light will be furnished by a 25-, a 40-, and a 100-wat lamp? (see table).

2. If we assume a living room to be 18 by 11 ft., and that it is to have an average illumination of 6 foot-candles, how many 25-watt lamps would be required? How many 100-watt lamps? Neglect various absorptions. If the watts multiplied by the time are a measure of the amount of electrical energy furnished, which installation is the more economical?

Lumens = foot-candles × area in square feet.

$= 6 \times 18 \times 11 = 1{,}188$

$\frac{1{,}188}{240}$ = number of 25-watt lamps required = 5 as least number.

$\frac{1{,}180}{1{,}340}$ = number of 100-watt lamps required = 1 as least number.

The 100-watt lamp will furnish 140 more lumens for four-fifths the energy.

3. A 50-watt lamp is at hand for the illumination of a room 10 by 12 ft. The desired illumination is to be 5 foot-candles. Neglecting absorptions will the lamp do this?

The lamp will furnish 525 lumens. The lumens required will be $10 \times 12 \times 5 = 600$.

4. What size study room can be illuminated to an average of 4 foot-candles by a 150-watt lamp when 65 per cent of the light is absorbed?

A 150-watt lamp will furnish 2,310 lumens and 35 per cent of this light is usable or 808.5 lumens.

Therefore:

$808.5 = 4x$, $x = 202.1$ sq. ft. as area of the room.

198. Measurements of Illumination and Brightness. *The Foot-candle Meter.*—Of the many different forms of instruments used for measuring illumination, the foot-candle meter is one of the simplest. The basic principle used is the same as that in the Bunsen photometer already described.

The screen consists of a piece of clear glass on which are pasted two sheets of paper, the one which contains the round

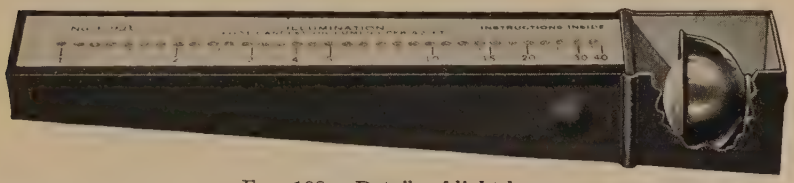


Fig. 108.—Details of light box.

holes is fairly opaque while the other is highly translucent. This screen forms the top of the light box which is so constructed that the light from the lamp gives a greater illumination on the right end of the screen than on the left end. The exposed side of the screen receives nearly uniform illuminaton and as a result the round spots appear brighter than the adjacent parts of the screen at the right end and darker toward the left end (see Fig. 109).

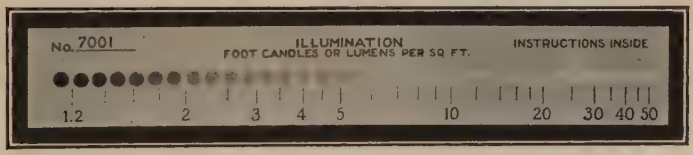


Fig. 109.—Screen indicating 5.5 foot-candles.

As in the Bunsen photometer, at the particular circle where the spot changes from being brighter than its background or darker than its background to the same intensity as the background, or where the spot most nearly disappears, the illumination falling on the top of the screen and that from beneath due to the lamp is the same. Figure 109 shows this condition for a given illumination. A scale of illumination in foot-candles can be obtained by allowing the light, say, from a 10-cp. lamp at different known distances to fall on the

photometer and noting the particular spot which disappears. It is evident that after the scale has been so calibrated the enclosed lamp must furnish at all times the same inside

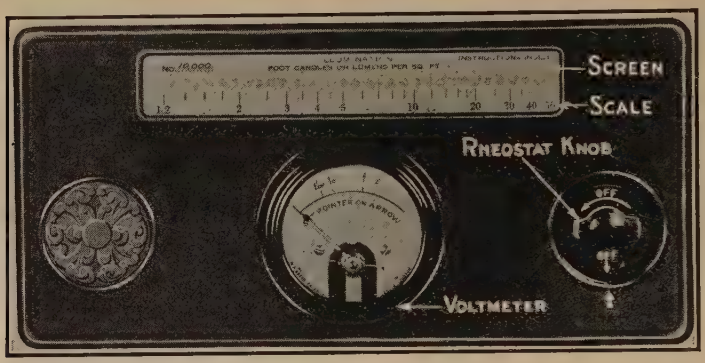


FIG. 110.—Foot-candle meter.

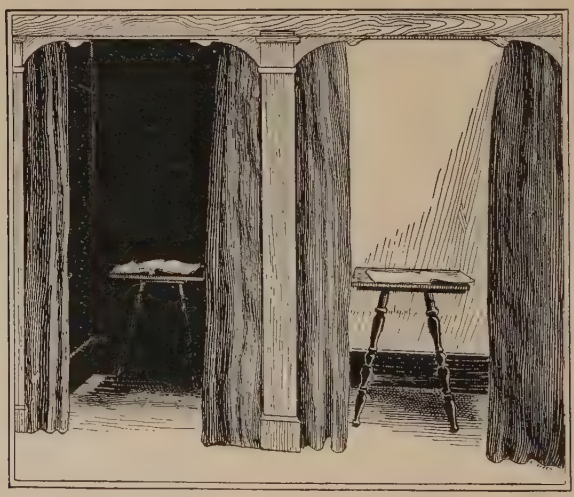


FIG. 111.—Showing difference in brightness with the same amount of light.

illumination as it did during the calibration. The instrument is provided with an adjustable resistance placed in series with the battery and lamp, and a voltmeter to determine the voltage at the lamp. If the lamp voltage is kept constant,

then the lamp will furnish the same illumination. To read low illuminations the voltmeter has another reference mark labeled 1/10. When this is used the readings on the scale are to be divided by 10 to obtain the correct value for the illumination. Figure 110 shows the foot-candle meter complete.

199. Brightness and Illumination Determinations.—The illustrations show the difference in the brightness of two rooms of the same size and shape, but with different ceiling and wall coverings, when each receives the same amount of light. The photographic method shows clearly the relative differences in brightness.

The sketch gives the illumination in foot-candles in different parts of a dining room, measured in a horizontal plane 30 in. above the floor. The illumination was determined by a foot-candle meter similar to the one described in the previous article.

200. Horizontal and Mean Spherical Candle Power.—The intensity of the light is not the same in all directions

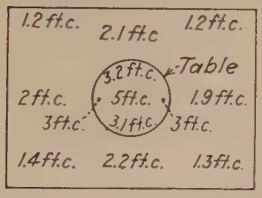


FIG. 112.—Illuminating values in a dining room.

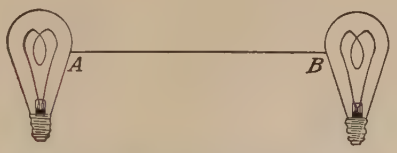


FIG. 113.—Horizontal and mean horizontal candle power.

around a lamp and so lamps are specified as to the candle power in three ways: *Horizontal candle power*, *mean horizontal candle power*, and *mean spherical candle power*

In the figure, if the intensity is measured in the direction AB, the horizontal candle power is found, but if the lamps are rotated about an axis perpendicular to AB in the plane of the paper and the intensity measured along AB, the mean horizontal candle power is obtained. Usually when a carbon lamp is spoken of as a 16-cp. lamp, it is the mean horizontal candle power that is meant. The same is true also of the tungsten when a 25-watt tungsten is said to give 20 cp.

A lamp gives light not only in a horizontal direction but in all directions, differing, however, in intensity.

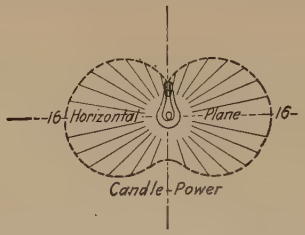


Fig. 114.—Mean spherical candle power showing distribution of light.

The mean spherical candle power is defined as the candle power which a lamp would have in all directions if the same

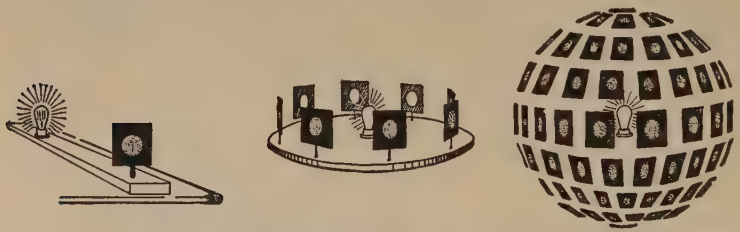


Fig. 114(*a*).—Illustrating horizontal, mean horizontal, and spherical candle power.

total amount of light were present but distributed evenly in all directions.

The following data were obtained by measuring the candle power of a carbon lamp, hanging vertically, in a number of planes 10 deg. apart. It shows clearly the differences in distribution.

Degrees	Candle power	Degrees	Candle power	Degrees	Candle power
0	3.0	60	14.5	120	14.5
10	5.0	70	15.2	130	13.0
20	7.5	80	15.6	140	11.3
30	9.8	90	16.0	150	9.5
40	11.5	100	15.8	160	8.1
50	13.3	110	15.3	170	7.0
				180	6.6

The table shows the mean horizontal and mean spherical candle power of two common types of lamps.

Lamp	Mean horizontal candle power (1)	Mean spherical candle power (2)	Ratio of $\frac{(2)}{(1)}$
Carbon	16	12.96	0.81
Tungsten	48	37.40	0.78

For general purposes of illumination the mean spherical candle power furnishes the better information concerning a given lamp.

The mean spherical candle power of a lamp multiplied by 12.57 will give the light output of the lamp in lumens.

Candle power values of lamps are rather rapidly disappearing and in their place the better rating in lumens is being used.

Study Exercises

1. A 20-cp. lamp is 4 ft. from a plane. What is the illumination in foot-candles coming to the plane?

2. A foot-candle meter is placed 3 ft. from the lamp in the above exercise. What is its reading?

3. A foot-candle meter 2 ft. from the lamp, reads 5 foot-candles. What is the candle power of the lamp?

4. A 10 cp. lamp is 1½ ft. above a study table. What illumination is being sent to the table?

5. A sewing table is to be given 10 foot-candles of illumination from a lamp 4 ft. above the table. What must be the candle power of the lamp?

6. A given wall surface has a reflecting power S of 25 per cent. What is the brightness of the wall when the illumination is 10 foot-candles?

7. A certain ceiling absorbs 40 per cent of the light. What illumination must be given it, if the brightness is to be 8 foot-candles?

8. A 1-cp. lamp is 1 ft. away from a surface 1 ft. square. How many lumens of light fall on the surface?

9. A surface 2 sq. ft. has 20 lumens of light falling on it. What is the illumination coming to the surface?

10. The mean spherical candle power of a certain lamp is 10. How many lumens is the lamp giving out?

11. A working space 10 by 15 ft. is to be illuminated to an intensity of 6 foot-candles. How many lumens must be given to the surface?

12. If a 60-watt lamp gives 575 lumens and 50 per cent of the light is wasted. How many such lamps will be required in exercise 11.

13. A satisfactory illumination for reading is 4 foot-candles. How far away may a 20-cp. tungsten lamp be placed?

14. A 40-watt tungsten lamp, giving 32-cp., is placed 4 ft. from a screen. What is the illumination on the screen?

15. A wall paper has a reflection coefficient of 50 per cent. What will be the brightness of the surface if a 48-cp. lamp is placed 5 ft. from the wall?

16. The mean horizontal candle power of a 100-watt tungsten lamp is 90. What is its mean spherical candle power?

17. Two lamps are 20- and 32-cp., respectively, and are 150 cm. apart. Where between the lamps must a Bunsen grease spot be placed to have its two sides equally illuminated?

Some Suggested Laboratory Exercises

1. Measurement of candle power of various kinds of lamps.
2. The distribution of illumination in the laboratory and in the home.
3. Determination of the relation between candle power, and the illumination at a point.
4. Change in candle power of a tungsten lamp with change of voltage, 105, 110, 115 volts.

REVIEW SUMMARY

Light is defined as those radiations which produce the sensation of sight.

Source of nearly all light is an incandescent body.

Light, in general, travels in straight lines.

Shadows and image in a pinhole are illustrations.

Intensity of a light source at a given point varies inversely as the square of the distance of the light from the point.

Luminous intensity is measured by making the illuminations due to the two sources at a given point equal. Then the candle power of the known lamp is to the candle power of the unknown intensity lamp *directly* as the squares of their distances from the common screen or point.

The Hefner lamp has by agreement a candle power of 0.9 the international candle.

The photometer—Bunsen determines the equality of illumination by the disappearance of the oil spot on the screen.

Law of the Photometer:

cp. : cp.′ :: cp′ distance squared : cp distance squared.

Illumination. Unit foot-candle.

$$\text{Foot-candle} = \frac{\text{candle power}}{d^2} = E.$$

Brightness = ES, where S is fraction of the total illumination which is *reflected* from a surface. Unit is the foot-candle.

The lumen measures the amount of light from a given source. The amount of light from a 1-cp. source 1 ft. distant from a screen 1 sq. ft. area, every point on the screen being perpendicular to the light, is, by agreement, 1 lumen.

The total amount of light from a 1-cp. source is 12.57 lumens.

Foot-candle meter, instrument for measuring illumination.

Horizontal candle power, the candle power as determined for one horizontal plane.

Mean horizontal candle power, the candle power determined from all the horizontal planes.

Mean spherical candle power, the candle power a lamp would have in all directions if the same total amount of light present were distributed *evenly* in all directions.

CHAPTER XX

ARTIFICIAL ILLUMINANTS

201. Brief Historical Sketch.—There can be little doubt but that the earliest source of artificial light was the wood fire where the lighting was, on the whole, incidental. As early as the time of Homer, torches of resinous wood in the form of long splinters were used, and this form of light continued to be used in some places even up to the middle of the nineteenth century. Following rather naturally came the use of the resinous substances in the wood, which were burned in open vessels. The use of vegetable and animal oils came only a little later. There is abundant evidence that lamps burning oil in open dishes date back nearly to prehistoric times. The use of wicks, sometimes of dry wood or wisps of grass, in these open vessels was an improvement and out of this grew the rush light, a wick soaked in oil, a primitive candle.

During the Middle Ages the wax candle and then the tallow candle were the common forms of light used except in the homes of the very poor. Indeed, the candle, well known to our grandparents, dominated the lighting of our homes until about 80 years ago, when the discovery of petroleum in America gradually brought the oil lamp into use. The oil lamp remains even today in many sections the most common type of illuminant.

Gas, which was first used for street lighting in London about 1810, came much later into the homes of the wealthier class, and, even with the development of the Welsbach mantel in 1885, has never won a very large place in residence lighting.

The carbon incandescent lamp was just entering the lighting field in 1880; the ordinary tungsten lamp came into use about 1900, and its modification, the gas-filled lamp, some 12 years

later. These two are rather rapidly displacing the carbon incandescent lamp because of their higher efficiencies.

202. Incandescence.—All of the lights mentioned have one common feature. They give out light because something is made very hot and emits light because of its hotness. In all these, the primary change is the transformaton of energy, chemical or electrical, into heat, which, in turn, being concentrated on a substance is partly transformed into light. It is interesting to note that, with one exception, the tungsten lamp, the substance which gets hot in all the lamps from the most primitive down to and including the ordinary electric lamp, is the same thing—carbon. Incandescent carbon is the great source of our light.

203. Flames.—In the candle, kerosene oil, and gas flames, the light is produced by the chemical energy of combustion of a hydrocarbon. If a gas flame is started, the gas burning at the surface of the burner, owing to its heat of combustion, produces a high temperature in the gas. The hydrocarbons under this high temperature split up into CH_4, H_2 and free carbon. Now these floating free carbon particles are made incandescent by the high temperature and radiate light. When they come into contact with the oxygen of the air they are consumed, forming CO_2 under ordinary conditions. The presence of the free carbon in all these flames is shown when a cold glass rod is passed through them. The rod is covered with soot.

Some hydrocarbons are extremely rich in carbon. When these are burned, for example, gasoline, in an open dish, they produce a smoky flame because the energy from the heat of combustion is not sufficient to raise the temperature of all the carbon to incandescence and so some escapes as soot or smoke. Our common kerosene lamp, using a hydrocarbon rich in carbon, smokes rather easily unless the flame is made of such a shape, flat or cylindrical, as to offer a large surface, which increases the rate of combustion. More air, too, is furnished for combustion by the use of the chimney.

204. Incandescent Solids.—In the case of the carbon and tungsten lamps the energy to produce incandescence, and so

light radiations, comes from the transformation of the electrical energy. In both these cases there is a gradual evaporation of the solid, the evaporated substance being largely deposited on the inside of the glass bulb, producing the blackening effect. The loss of the solid gradually causes the filament to break and ends the life of the lamp.

205. Luminescence. Cold Light.—We are all more or less familiar with the fact that light can be produced without much, if any, heat. The phosphorescent light seen at times on the ocean, that from certain fish, the light from the glow-worm and the firefly, in certain gases when subjected to an electric discharge, and from some substances after they have been subjected to other sources of light, are all examples of luminescence or cold light.

We have seen that light is produced by the transformation of one kind of energy into two others, usually heat and light. In luminescence, the transformation is entirely, or very largely, into one kind of energy, light, and as the heat energy is wasted as far as the light is concerned, luminescence is, in theory, the most efficient form of light. So far in practice, however, it has been found, with a few exceptions, impossible to attain this increased efficiency and there is no probability that luminescence will in the near future be used in home lighting.

206. Temperature Radiation.—All bodies are sending out energy into space in the form of radiations or ether waves of various lengths. Let us consider a coil of platinum wire at a temperature of 100° C. Our eyes give us no information concerning any radiations coming from it and our temperature sense gives but little, if any, indication. If an instrument called a "radiometer" is placed near the coil, the little vanes are seen to increase their speed of revolution. It is evident that something is being sent out from the coil to the radiometer. As we have already seen, the coil is the source of heat radiations of low intensity and long wave length. If the coil is heated to a higher temperature by passing an electric current through it, the speed of the vanes on the radiometer is increased, showing that the intensity of the radiations is

greater. The frequency of the ether vibrations is also increased with a decrease in the length of the waves.

With increasing temperature, the two changes just mentioned continue until the wave length of some of the radiations sent out becomes about 0.0008 mm., when the eye can detect a faint red light coming from the coil. The radiations are now visible, or light radiations. Further increase of temperature, if the coil is placed in front of a spectro-photometer, shows that the visible radiations are passing through the range of spectral colors toward the violet, of wave length about 0.0004 mm., and finally, white light, all the visible radiations are now present. If we cut out all these visible radiations coming from the coil, we find that there are still coming from the coil the longer heat radiations. Theory indicates that if the temperature of a hot body were somewhere about 6000° C., then approximately 50 per cent of the energy given to the body would be in the visible radiations and 50 per cent in the heat radiations. The sun represents the closest approach to this condition. Carbon, the most refractory substance, boils at about 3700° C., and we cannot, therefore, make use of this high temperature.

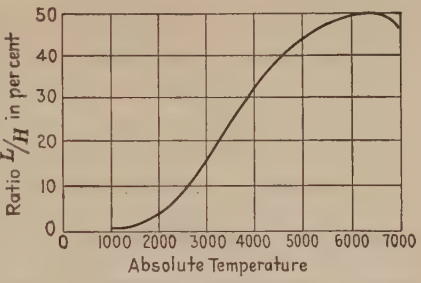


FIG. 115.—Effect of temperature on energy radiated as light.

207. Luminous Source. A luminous source is one that radiates some of its energy within the visible spectrum, between wave lengths 0.0008 and 0.0004 mm. One question about every luminous source is: what part of the total energy being radiated is in visible radiations? As we have seen, one factor which determines this is the temperature. If a black body at 2000° C. has its temperature increased 1 per cent, to 2020° C., the total energy radiated is found to have been increased about 4 per cent, but the amount of energy now radiated in the visible spectrum has increased about 10 per cent. If L equals the amount of energy radiated as light and

H the total energy radiated, then the ratio of $L : H$ at different temperatures gives one condition for obtaining efficient light. The curve shows that the greatest proportion of the energy is radiated in the visible spectrum when the temperature of the body is about 6000° C. But at this high temperature only 50 per cent of the radiations are in the visible spectrum.

208. Sensibility of the Eye.—The eye as the receiving instrument must be considered. We might expect that if radiations of twice the intensity come to the eye, the sensation would be doubled. But the relation between intensity of the stimulus and the intensity of the sensation depends upon the particular wave length or radiation rather than the amount of energy in that radiation.

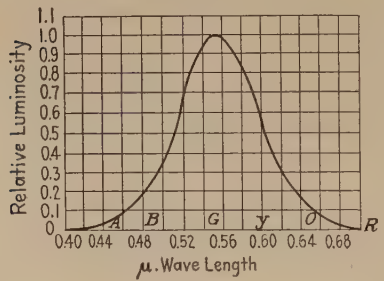


FIG. 116.—Relation between wave lengths and intensity of the sensation.

The curve shows that light of wave length 0.000555 mm. in the yellow-green will produce the maximum sensation on the eye for a given stimulus. Unfortunately, its color makes it unsuitable for general illumination even if substances were known which would radiate this wave length only.

209. Selective Radiation.—In the section on Heat, attention was called to the fact that different surfaces have different radiating abilities. An ideal black body is one that would absorb and radiate equally all the different kinds of radiations coming to it. Actual bodies all depart from the ideal black body to a greater or less extent. Theoretically it is possible to imagine a body which, on having its temperature raised to a certain value, would radiate *all* its energy in the visible spectrum. This would be an example of ideal selective radiation. No actual body does this, but if one of two equally hot bodies, by selective radiation, sends out in light radiations a greater part of its total energy than the other, it would be the more efficient light radiator. The facts at present seem to show

that both carbon and tungsten, the two kinds of filaments most used, have selective radiation and that the selective radiation of the tungsten is such as to make it a slightly better radiator than is carbon. The most important factor in making the tungsten lamp more efficient than the carbon lamp is the fact that it can be run at a higher temperature. The temperature of the carbon filament is about 1900° C. and that of the tungsten filament from about 2100 to 2600° C.

210. Efficiencies of Incandescent Sources.—What would be the most efficient light source that could be imagined? It would evidently be, from the general discussion which has been given, one in which all the energy supplied is transformed into radiation and all this radiation is of wave length 0.000555 mm. The efficiency under these conditions would be according to the best data at present such as to give 1 mean horizontal candle power for 0.012 watt, or 1 mean spherical candle power for 0.015 watt. This light being a yellowish green would be entirely unsatisfactory for general illumination purposes. A more interesting question is, what would be the highest possible efficiency of a white light if all the energy were transformed into radiations within the visible spectrum and of a color value similar to that of the average noon-time sunlight. The answer is 0.040 watt per mean spherical candle power or 0.031 watt per mean horizontal candle power. The wide difference between the theoretically most efficient light source and the actual sources is shown in the table:

Source	Watts per Mean Horizontal Candle Power
Ideal yellow-green source	0.012
Ideal white source	0.031
Carbon lamp	3.100
Tungsten	1.250
Gas-filled tungsten	0.600
Kerosene	43.0

If we call the efficiency of the ideal white source 100 per cent, then the efficiency of the carbon lamp is 1.0 per cent, that of the ordinary tungsten 2.4 per cent and that of the gas-filled tungsten lamp about 5.1 per cent.

The reasons for the low efficiencies of artificial lamps are: (1) not all the energy given to the lamp is given out as radiant energy, some is lost by convection and conduction; (2) a part only of the radiant energy is in the visible radiations, a large amount is in the longer heat radiations; (3) the energy within the visible spectrum is not confined to those radiations of greatest luminosity.

211. The Gas-filled Tungsten Lamp.—This lamp, which made its first appearance about 1912, is a tungsten filament in an atmosphere of an inert gas under rather high pressure. The gas helps to reduce the rate of evaporation of the tungsten even though it is run at a temperature of 400 to 600° degrees higher than the vacuum lamp. It is the evaporation which produces the blackening, as we have seen, in the carbon as well as in the vacuum tungsten lamps. If carbon could be heated in an atmosphere of some gas which would not unite with it, then it could be run at a higher temperature than the tungsten and would be the more efficient.

The tungsten lamps would be more efficient if run at temperatures nearer the melting point of the tungsten but the life of the lamps would be much less. So the extra cost of lamps would more than equal the decreased cost of the light.

212. Cost of 1,000 Candle Hours.—The number of different types of lamps now available for the production of light is very great and one of the factors in deciding on what kind of lamp to use is the cost of the production of the light.

Illuminant	Cost per 1,000 Candle Hours
Candles, at 15 cts. a pound	$2.50
Kerosene, at 15 cts. a gallon	0.20
Kerosene, using a mantle, cost of mantle	0.07
Gas, ordinary batwing burner, gas $1 per 1,000 cu. ft.	0.25
Gas mantle, cost of mantle, gas $1 per 1,000 cu. ft.	0.06
Carbon, incandescent, electricity 10 cts. per kw.-hr.	0.35
Tungsten, 1.25 watts per candle, vacuum, plus 30 cts. for lamp, electricity 10 cts. per kw.-hr.	0.13
Tungsten, 0.7 watt per candle, gas filled, $1 for lamp, electricity, 10 cts. per kw.-hr.	0.076
Acetylene, carbide $60 a ton	0.30

One thousand candle power hours may be obtained from a 1 cp. lamp burning for 1,000 hours, a 10-cp. lamp burning for 100 hours, or any combination of candle power and time that equals 1,000.

The tungsten lamp is rapidly displacing the carbon lamp in home lighting; but too many still use the carbon lamp because light companies often give a free renewal of the carbon lamps but charge for the tungsten, and because the early tungsten lamps were rather fragile. The tungsten lamps now are robust, as shown by their use in street cars and automobiles where they are constantly subjected to jars. A comparison of the cost of using the two is interesting. Two 16-cp. carbon lamps will require 100 watts and, if their life is 1,000 hours, will consume 100,000 watt-hours or 100 kw.-hr. of electrical energy. If the charge is 10 cts. per kw.-hr., then the cost for 32 cp. for 1,000 hours is $10. Now 1 40-watt tungsten lamp will give 32 cp. and the cost for the same amount of light for the same time will be $4; adding 30 cts. for the tungsten lamp makes the total cost $4.30, or a saving of $5.70. If the tungsten lamp burns but 50 hours, the cost of the lamp has been saved. The table (**Art. 197**) shows that where the lighting fixture will permit, one 150-watt lamp will give more lumens than four 50-watt lamps.

213. By-products from Flame Illuminants.—All flame illuminants have the disadvantage of consuming oxygen from the air and of giving off carbon dioxide and moisture. The table gives some idea of the amounts of these products.

Illuminant	Amount consumed per hour	Candle power	Oxygen removed; cubic feet	Carbon dioxide produced; cubic feet	Moisture produced, cubic feet	Heat liberated, calories	Vitiation of air produced equal adult persons
Sperm candles	1,740 gr.	16	10.7	7.3	8.2	1,400	12
Kerosene	909 gr.	16	5.9	4.1	3.3	1,030	7
Gas	6 cu. ft.	16	6.5	2.8	7.3	11.94	5
Gas with mantle	4 cu. ft.	50	4.1	1.8	4.7	763	3

214. Color Characteristics of Illuminants.—The ideal color for artificial illuminants would, of course, be that of sunlight.

All the artificial illuminants differ in their color values from that of daylight. There are different ways of making a comparison of the color differences of illuminants. The data given below, taken from the work done in the Nela Research Laboratory, show the spectral distribution of energy in the visible region for different illuminants. The data are obtained by making the relative energy of wave length 0.00059 mm. equal 100 for all the illuminants. This gives the relative distribution of energy for nearly the same amounts of total light sensation. The data for the two tungsten lamps show clearly the effect of temperature on the relative amounts of short wave lengths emitted.

Wave length	Red	Orange	Yellow	Green	Blue	Violet
	0.00069	0.00061	0.00059	0.00051	0.00045	0.00041
Average daylight....	93.5	100	100	96	84.3	72
Carbon, 3.1 watts per mean horizontal candle power.....	234	123	100	34.5	12	4
Tungsten, 1.25 watts per mean horizontal candle power	202	117	100	42.6	16.7	
Tungsten, 0.5 watts per mean horizontal candle power gas-filled lamp....	147.5	111	100	56.5	30	16.5
Welsbach gas mantle	120	107	100	51	17.5	
Direct-current arc...	170	113.5	100	55	29	

It would be difficult to predict what the effect of these differences would be on the various color combinations found in the home. But an instrument called a "lumichromoscope" will enable us to see the effect on a given set of colors. A box, which is divided into a number of compartments by vertical partitions, has its base covered with narrow, colored ribbons, running the entire length. In the ceiling of each compartment is placed a different illuminant. The appearance of the different colors under different lights is easily seen.

Because all artificial illuminants produce changes in the appearance of colored objects, there have appeared in recent years the so-called "daylight" lamps. These lamps are arranged so that the light passes through a colored film which takes out the *excess* of the colored elements in the light. A glance at the table above indicates that all the artificial light sources, as compared with sunlight, have an excess of the colors at the red end of the spectrum. This will account for the bluish color of the film or screen used in such lamps. With these daylight lamps even the more elusive hues may be matched under them. Picture galleries, art museums, and even some homes are being illuminated by such lights.

REVIEW SUMMARY

Early sources of artificial light, wood fire, splinters of resinous wood as torches, burning of vegetable and animal oils, then the addition of wicks made a great improvement. In the Middle Ages came the candle, still used; about 80 years ago the kerosene lamp, and gas lamps; and in 1880 the carbon incandescent lamp. This was followed about 1900 with the tungsten lamp.

All these sources, except the tungsten lamp, produced light from incandescent carbon.

Luminescence, cold light, firefly, some artificial sources, transformation of energy largely into light, little heat.

Temperature radiations, largely heat, small amount of light. The proportion which is light increases rapidly with an increase in temperature.

The eye not equally sensitive to light of different wave lengths or frequencies. Most sensitive to light of wave length about 0.000555 mm. Color objectionable.

Efficiency of the ideal white light 0.031 watt per mean horizontal candle power. The gas-filled tungsten lamp of 1.25 to 0.6 watts per mean horizontal candle power the most efficient of the light sources used in the home. Efficiency here means ratio of light energy radiated to the total amount of energy radiated.

CHAPTER XXI

HOME LIGHTING

215. The Problem.—The satisfactory lighting of the home involves the consideration of many factors from the fields of physics, physiology, psychology, and art, some rather definitely determined and many as yet so indefinite that no hard and fast rules can be laid down.

Some of the fundamentals which should be observed are: first, the light should produce eye comfort. No glare or great brilliancy with its attendant eyestrain should be permitted. Extreme contrasts in light are bad, very dark areas and very bright ones adjacent are not pleasing. Second, the lighting fixture should be as much a part of the room as the draperies, the carpet, or the furniture.

The discussions in this chapter will deal with the factors which control the first of the two fundamentals named.

216. Globes, Shades, and Reflectors.—The usual types of lamps are not only unsatisfactory when bare, but produce *serious eyestrain*, and globes, shades and reflectors are used to improve them in the following ways:

1. To decrease the intrinsic brilliancy of the illuminant.
2. To control the distribution of the light.
3. To soften the shadows, lessen contrasts.
4. To give some decorative effect to the lamp.

217. Intrinsic Brilliancy.—Intrinsic brilliancy refers to the intensity of the light source per unit area. A 16-cp. carbon lamp has an intensity of 300 to 500 candles for each square inch of incandescent carbon filament; a kerosene lamp has an intrinsic brilliancy of 3 to 8 candles per square inch of flame area; a gas mantle, of 20 to 40 candles per square inch; and a vacuum tungsten lamp of 850 to 1,050 candles per square inch; while the gas-filled tungsten is about eight times more brilliant.

There is general agreement that all our modern illuminants are too high in intrinsic brilliancy and that direct light from the lamp should never reach the eye. Just what intrinsic brilliancy is permissible is not certain. Some writers give 4 to 5 cp. per square inch of luminous source, while others go as low as 0.1 to 0.2 cp. per square inch. These differences are probably due to the neglect of the effect of contrast. A brilliancy of 3 cp. per square inch may produce less eyestrain than one of 0.2 cp. if there is less excessive contrast of brightness in the first case than in the second. A bare carbon or tungsten lamp when lighted in a daylight room produces little or no discomfort. The relative brightness of the lamp and the room is not great.

Globes and shades tend to reduce intrinsic brilliancy partly by absorbing some of the light and more by increasing the areas of the luminous source. If a 25-watt tungsten lamp is enclosed in a 6-in. opal globe, the globe becomes the luminous source for the eye and, as its area is many times that of the tungsten filament, roughly say as 1:10,000, the intrinsic brilliancy is correspondingly reduced. Many types of globes and shades used in the home have little effect in reducing the intrinsic brilliancy. In general, when the outline of the filament can be seen distinctly through the shade, it will not reduce the brilliancy a satisfactory amount. In many of the bowls used in the semi-indirect system of lighting the intrinsic brilliancy of the bowl is far too large.

The absorption of some of the various materials used as shades is given in the table:

	Percentage
Clear glass	10
Alabaster glass	15
Opaline	20 to 40
Ground glass	20 to 35
Opal	25 to 60
Milky glass	30 to 60
Colored paper and silk	50 and up

Too much attention must not be given to the loss of light due to absorption because it is one of the chief factors in reducing the too great brilliancy with its resulting eye strain.

218. Distribution.—A shade, strictly, is a device for changing the intensity of a light, and a reflector, a device for changing the distribution of the light. In practice, these two are combined, sometimes with the emphasis on the shade

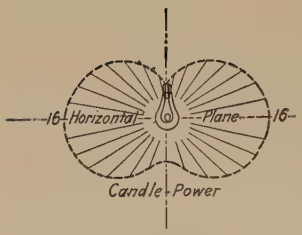


FIG. 117.—Distribution of light around a bare lamp.

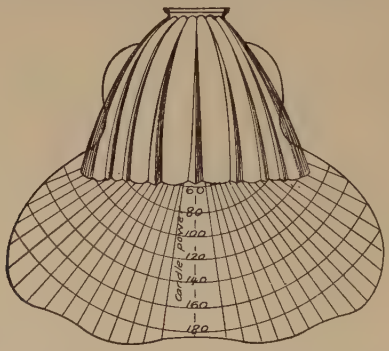
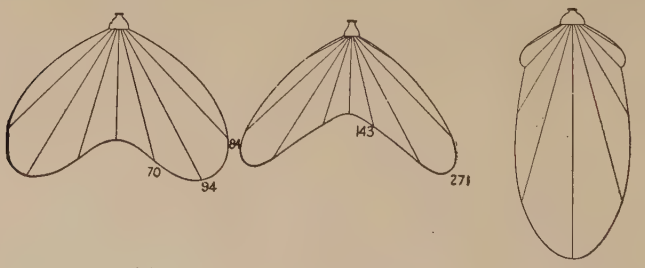


FIG. 118.—Effect of a reflector on the distribution of the light from the lamp in Fig. 117.

characteristics and sometimes on the reflector factor. The first figure shows the distribution of the light from a bare tungsten lamp; the second shows the distribution of the light from the same lamp when a white opal reflector is used:



(*a*) Distributing. (*b*) Distributing. (*c*) Concentrating.

FIG. 119.

Although some of the light is absorbed by the reflector, its most important use has been to reflect a large part of the light from the bare lamp in the downward direction. The length of the lines in the different directions is proportional to

	COLOR REFLECTION FACTOR: CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
	WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE / ROOM INDEX	COEFFICIENTS OF UTILIZATION							
8	LIGHT DENSITY OPAL Clear Lamp 90° to 180°—33% 0° to 90°—54%	0.6 .26	.21	.17	.24	.19	.16	.18	.15
		0.8 .32	.27	.23	.30	.25	.22	.24	.21
		1.0 .36	.31	.27	.34	.29	.26	.27	.24
		1.25 .40	.35	.31	.37	.32	.29	.30	.27
		1.5 .44	.38	.34	.40	.35	.32	.32	.30
		2.0 .49	.44	.39	.45	.40	.37	.37	.34
		2.5 .53	.48	.44	.49	.44	.41	.40	.38
		3.0 .56	.51	.47	.51	.46	.43	.42	.40
		4.0 .60	.55	.51	.55	.50	.47	.46	.44
		5.0 .62	.58	.54	.57	.53	.50	.48	.46
9	LIGHT DENSITY OPAL Bowl-Enameled Lamp 90° to 180°—36% 0° to 90°—45%	0.6 .22	.17	.14	.20	.16	.13	.14	.12
		0.8 .27	.22	.19	.25	.21	.18	.19	.16
		1.0 .31	.26	.23	.28	.24	.21	.22	.19
		1.25 .35	.30	.26	.31	.27	.24	.24	.22
		1.5 .38	.33	.29	.34	.30	.26	.27	.24
		2.0 .43	.38	.34	.38	.34	.31	.30	.28
		2.5 .47	.42	.38	.42	.38	.34	.34	.31
		3.0 .49	.44	.40	.44	.40	.37	.36	.33
		4.0 .53	.49	.45	.48	.44	.41	.39	.37
		5.0 .56	.52	.48	.50	.46	.43	.40	.39
10	DENSE OPAL Clear Lamp 90° to 180°—15% 0° to 90°—67%	0.6 .32	.27	.23	.31	.26	.22	.25	.22
		0.8 .40	.35	.31	.38	.34	.31	.33	.30
		1.0 .44	.39	.36	.42	.38	.35	.37	.35
		1.25 .47	.43	.40	.46	.42	.39	.40	.38
		1.5 .51	.47	.43	.49	.45	.42	.43	.41
		2.0 .56	.52	.48	.54	.50	.47	.48	.46
		2.5 .60	.56	.53	.57	.54	.52	.52	.50
		3.0 .63	.59	.55	.60	.56	.54	.54	.52
		4.0 .66	.63	.60	.63	.60	.58	.57	.55
		5.0 .67	.65	.62	.65	.61	.59	.59	.57
11	DENSE OPAL Bowl-Enameled Lamp 90° to 180°—16% 0° to 90°—60%	0.6 .29	.24	.20	.28	.23	.20	.22	.20
		0.8 .35	.31	.28	.34	.30	.27	.29	.27
		1.0 .39	.35	.32	.38	.34	.32	.33	.31
		1.25 .43	.39	.36	.41	.38	.35	.36	.34
		1.5 .46	.42	.38	.44	.40	.37	.38	.36
		2.0 .51	.47	.44	.48	.45	.42	.43	.41
		2.5 .55	.51	.48	.52	.49	.46	.47	.45
		3.0 .57	.54	.50	.54	.51	.48	.48	.46
		4.0 .60	.57	.54	.57	.54	.52	.51	.50
		5.0 .62	.59	.56	.58	.56	.54	.53	.52
12	MIRRORED GLASS Clear Lamp 90° to 180°—0% 0° to 90°—68%	0.6 .32	.27	.24	.31	.27	.24	.27	.24
		0.8 .39	.35	.32	.39	.35	.32	.35	.32
		1.0 .43	.39	.37	.42	.39	.37	.39	.37
		1.25 .46	.43	.40	.46	.43	.40	.42	.40
		1.5 .49	.46	.43	.48	.45	.43	.45	.43
		2.0 .53	.50	.48	.52	.50	.48	.49	.48
		2.5 .57	.54	.52	.56	.54	.52	.53	.52
		3.0 .58	.56	.54	.57	.55	.54	.54	.53
		4.0 .61	.59	.57	.60	.58	.56	.57	.56
		5.0 .63	.61	.58	.61	.59	.58	.58	.57
13	MIRRORED GLASS Bowl-Enameled Lamp 90° to 180°—0% 0° to 90°—55%	0.6 .26	.22	.19	.25	.22	.19	.21	.19
		0.8 .32	.29	.26	.31	.28	.26	.28	.26
		1.0 .35	.32	.30	.34	.32	.30	.31	.30
		1.25 .38	.35	.33	.37	.35	.33	.34	.33
		1.5 .40	.37	.35	.39	.37	.35	.36	.35
		2.0 .43	.41	.39	.42	.40	.39	.40	.39
		2.5 .46	.44	.42	.45	.43	.42	.43	.42
		3.0 .47	.46	.44	.46	.45	.44	.44	.43
		4.0 .49	.48	.46	.48	.47	.46	.46	.45
		5.0 .50	.49	.47	.49	.48	.47	.47	.46
14	PRISMATIC INDUSTRIAL Clear Lamp 90° to 180°—18% 0° to 90°—73%	0.6 .33	.26	.21	.31	.25	.21	.24	.20
		0.8 .41	.35	.30	.39	.33	.29	.32	.29
		1.0 .45	.40	.35	.43	.39	.34	.37	.33
		1.25 .50	.44	.39	.47	.42	.38	.40	.37
		1.5 .52	.48	.43	.50	.45	.42	.43	.40
		2.0 .58	.54	.49	.56	.51	.47	.49	.46
		2.5 .63	.59	.54	.60	.56	.53	.54	.51
		3.0 .66	.62	.58	.63	.59	.56	.56	.54
		4.0 .71	.67	.63	.67	.63	.61	.60	.58
		5.0 .73	.69	.66	.69	.65	.63	.62	.60

FIG. 120(*a*).

	COLOR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
22	LIGHT OPAL	0.6	.18	.14	.11	.15	.12	.09	.09	.07
		0.8	.22	.18	.15	.19	.15	.12	.12	.10
		1.0	.26	.22	.18	.22	.18	.15	.14	.12
		1.25	.30	.25	.22	.25	.21	.18	.16	.14
		1.5	.33	.28	.24	.27	.23	.20	.18	.16
	90° to 180°—60%	2.0	.38	.33	.29	.31	.27	.24	.21	.19
		2.5	.41	.36	.32	.34	.30	.27	.24	.22
		3.0	.44	.39	.35	.36	.32	.29	.25	.23
		4.0	.49	.44	.40	.40	.36	.33	.28	.26
	0° to 90°—25%	5.0	.51	.46	.42	.42	.38	.35	.29	.28
23	DENSE OPAL (or Light Opal and Bowl-enameled Lamp)	0.6	.16	.13	.11	.12	.10	.08	.07	.06
		0.8	.20	.17	.15	.16	.13	.11	.09	.08
		1.0	.23	.20	.17	.18	.15	.13	.10	.09
		1.25	.27	.23	.20	.21	.18	.16	.12	.11
		1.5	.29	.26	.22	.23	.19	.17	.13	.12
	90° to 180°—70%	2.0	.33	.29	.26	.26	.22	.20	.15	.14
		2.5	.36	.32	.29	.28	.25	.23	.17	.16
		3.0	.39	.35	.32	.29	.27	.25	.18	.17
		4.0	.43	.39	.36	.32	.30	.28	.20	.19
	0° to 90°—10%	5.0	.45	.41	.38	.34	.32	.30	.22	.20
24	ENAMELED METAL REFLECTOR Opal Glass Bottom	0.6	.16	.13	.11	.12	.10	.08	.07	.06
		0.8	.19	.16	.14	.15	.13	.11	.08	.08
		1.0	.22	.19	.17	.17	.15	.13	.10	.09
		1.25	.25	.22	.19	.20	.17	.15	.11	.10
		1.5	.27	.24	.21	.21	.18	.16	.12	.11
	90° to 180°—49%	2.0	.31	.28	.25	.24	.21	.19	.14	.13
		2.5	.34	.31	.28	.25	.23	.22	.15	.15
		3.0	.36	.33	.31	.27	.25	.23	.16	.15
		4.0	.40	.37	.34	.29	.28	.26	.18	.17
	0° to 90°—6%	5.0	.41	.38	.37	.31	.29	.28	.19	.18
25	PRISMATIC ENCLOSED	0.6	.19	.15	.12	.16	.13	.10	.10	.09
		0.8	.24	.20	.17	.20	.17	.14	.14	.12
		1.0	.27	.23	.20	.23	.19	.17	.16	.14
		1.25	.31	.27	.23	.26	.22	.20	.18	.16
		1.5	.34	.29	.25	.28	.24	.22	.20	.18
	90° to 180°—57%	2.0	.38	.34	.30	.32	.28	.25	.22	.20
		2.5	.41	.37	.34	.34	.31	.28	.25	.23
		3.0	.44	.40	.36	.36	.33	.30	.26	.24
		4.0	.48	.44	.41	.40	.36	.34	.29	.27
	0° to 90°—26%	5.0	.50	.46	.43	.42	.38	.36	.30	.29
26	CLEAR TOP ENCLOSED Enameled Glass Bowl	0.6	.16	.12	.10	.13	.10	.08	.07	.06
		0.8	.20	.16	.13	.17	.13	.11	.10	.09
		1.0	.23	.19	.16	.19	.15	.13	.12	.10
		1.25	.26	.22	.19	.21	.18	.15	.14	.12
		1.5	.29	.25	.21	.24	.20	.17	.15	.13
	90° to 180°—54%	2.0	.32	.28	.25	.26	.23	.20	.18	.16
		2.5	.36	.31	.28	.29	.26	.23	.20	.18
		3.0	.38	.34	.31	.31	.28	.25	.22	.20
		4.0	.42	.38	.35	.34	.31	.29	.24	.22
	0° to 90°—21%	5.0	.44	.40	.37	.36	.33	.31	.25	.24
27	MIRRORED INDIRECT	0.6	.15	.12	.10	.11	.09	.07	.05	.04
		0.8	.18	.15	.13	.13	.11	.09	.07	.06
		1.0	.22	.19	.16	.15	.13	.11	.08	.07
		1.25	.25	.22	.19	.18	.15	.13	.09	.08
		1.5	.27	.24	.21	.20	.17	.15	.10	.09
	90° to 180°—80%	2.0	.30	.27	.25	.22	.19	.17	.11	.10
		2.5	.34	.31	.28	.24	.22	.20	.13	.12
		3.0	.36	.33	.30	.26	.24	.22	.14	.13
		4.0	.40	.37	.34	.28	.26	.24	.15	.14
	0° to 90°—0%	5.0	.42	.39	.37	.30	.28	.26	.17	.15
28	ENAMELED METAL INDIRECT	0.6	.14	.11	.10	.10	.08	.07	.04	.04
		0.8	.17	.14	.13	.13	.10	.09	.06	.05
		1.0	.20	.17	.15	.14	.12	.10	.07	.06
		1.25	.23	.20	.17	.17	.14	.13	.08	.07
		1.5	.25	.22	.19	.18	.15	.14	.09	.08
	90° to 180°—74%	2.0	.28	.25	.23	.21	.18	.16	.10	.10
		2.5	.31	.28	.26	.22	.20	.18	.12	.11
		3.0	.33	.30	.28	.24	.22	.20	.13	.12
		4.0	.37	.34	.32	.26	.24	.22	.14	.13
	0° to 90°—0%	5.0	.39	.36	.34	.28	.26	.24	.15	.14

FIG. 120(*b*).

the candle power in that direction. Reflectors may be obtained to give almost any desired type of distribution, but the two most common types are those shown in Fig. 119, the concentrating and distributing types.

The general character of the distribution of light produced by various types of shades and reflectors is shown on pages 251 and 252.

219. Absorption Table.—The percentage of light absorbed from mazda lamps by various colored walls and ceilings.

White paper	16	Ivory	27	Forest green	84
Ivory white	23	Ivory tan	44	Olive green	79
Light gray	30	Buffstone	63	Pale azure	61
Lichen gray	31	Buff	40	Sky blue	64
Pearl gray	27	Tan	72	Shell pink	49
Silver gray	49	Satin green	37	Pink	50
Battleship gray	80	Bright sage	57	Cardinal red	84

Surfaces which absorb 30 per cent or less are considered very light, fairly light if the absorption is around 50 per cent fairly dark when it is 70 per cent, and very dark when it is 90 per cent.

220. Coefficients of Utilization.—Light is lost by the absorption of the enclosing reflector or shade, by the fixture, by the walls and ceiling. Hence only a portion of the lumens emitted by the lamp reach the plane where light is desired.

The proportions of the room, and the color of the walls and ceiling are important factors in determining the amount of light which is usable.

From a series of extensive tests made on rooms of various dimensions, it has been found possible to classify luminaires into groups, depending upon room length, width, and the distance from the plane to be illuminated to the luminaire. This classification in the tables in Fig. 120(*a*) and (*b*), is given as the Room Index.

To illustrate how illumination engineers use these tables, some data will be worked out in detail.

1. For a living room 20 by 20 ft. with a 9-ft. ceiling, a *direct-type* luminaire is to be hung so it is 4 ft. above the plane to be illuminated, which is assumed to be 2.5 ft. above the floor.

Then the index is:

$$\text{Index} = \frac{\text{width of room}}{2 \times \text{height from working plane to lamp}},$$

$$= \frac{20}{2 \times 4} = 2.5.$$

Using luminaire No. 8 in the table, assuming a very light ceiling and fairly dark walls, index 2.5, shows that the coefficient of utilization is 0.48.

If it is desired that the working plane have an average intensity of 3 foot-candles, the lumens actually delivered must be $20 \times 20 \times 3$, or 1,200 lumens. Since 1,200 lumens represents 48 per cent of the light emitted, the lamp must be one which emits, 2,500 lumens.

2. If the same room is to be illuminated by a semi-indirect or indirect luminaire, the room index equals:

$$\frac{\text{Width of room}}{1\frac{1}{3} \times \text{height from plane of work to ceiling}} = \frac{20}{1\frac{1}{3} \times 6} = 2.3.$$

Using luminaire No. 23, for this room, we find the efficiency of utilization is between 29 and 32 per cent. Then 1,200 lumens equal 31 per cent of the lumens to be furnished or the lamps must supply 3,870 lumens.

When the room is not square, the room index cannot be found from the relations above, but must be taken from tables made up from many direct experiments. Such tables are found in books on illumination.

3. If the living room is 24 by 14, but all the other conditions are the same as in Problem (1), the room index as given in tables is 2 and the utilization efficiency for luminaire No. 8 is found to be 44 per cent. This room then absorbs a little more of the light than the square room.

Study Exercises

1. A kitchen 10 by 10 is to be lighted by an inclosed luminaire of light opal. The room index is 0.8 and the utilization efficiency is 22 per cent. If the illumination on the working plane is to be 4 foot-candles, what size lamp should be used?

2. A dining room 16 by 14, light ceiling and walls, and trim fairly dark, is to be illuminated to an average of 5 foot-candles by the No. 24 luminaire. The utilization efficiency, room index 1.8, is, as shown, 26 per cent. What sized lamp should be used?

3. A living room 16 by 24, is lighted by two floor lamps and one piano lamp by luminaires No. 27. The ceiling is light and the walls an ivory tan. The index may be taken as 2, and the utilization efficiency as shown in the table is 30 per cent. An average illumination of 3 foot-candles is desired. Two 100-watt lamps and one 75-watt lamp are used. Will they give the desired illumination?

221. Glare.—Good illumination is one of the most important factors in the conservation of eyesight and in producing eye

comfort. Glare, on the other hand, is not only the *most common and serious defect* in lighting, but it is least understood. Glare has so many aspects that it is difficult to define, but we will first define it as dazzling light which confuses the sight. In physiological terms, glare is the discomfort of the visual functions due to light out of place. The blinding effect on first going out into bright sunlight, the glare from snow, the reflection from water, or from a white building with glazed walls, the discomfort from the bare lamp or the usual wall-bracket light, are all familiar examples of glare.

222. Glare Producers.—The chief factors in producing glare are: (1) *excessive brightness*, (2) *excessive volume of light*, (3) *excessive contrast.*

We have already discussed the glare produced by too great intrinsic brilliancy of the source. An excessive volume of light may come from sources having a low intrinsic brilliancy. A birthday cake lighted with small candles and placed on a small dinner table can produce great eye discomfort, although the intrinsic brilliancy is low and so is the total amount of light. The nearness to the source in this case allows a too great volume of light to enter the eye. A semidirect bowl of 16-in. diameter will permit a greater amount of light to enter the eye than will a 12-in. bowl, even when the intrinsic brilliancy of the bowls is the same.

The first two glare factors may be absent and yet glare may come from excessive contrast. A brilliantly lighted dinner table with a dimly lighted dining room can produce eye discomfort and eye strain resulting in a bad headache the morning after. Students frequently study in a dark room with an excessively lighted study table. Again glare results.

223. Glare Conditions.—When a glare source is present, due to any of the factors just discussed, there are three conditions not associated with either the source of the light nor the condition of the eyes which determine the amount of seriousness, to an observer:

(*a*) *The angle which the source of glare makes with the line of vision of the observer.* It is obvious, if the light source is directly overhead, its brightness or its amount will not produce

glare. As the angle between the source and the eye decreases, the glare becomes more serious and it will be a maximum when the angle is zero, that is, when one is looking directly at the source. For any given angle the glare is greatest when the light source is *below* the eye and least when it is *above* the eye. The line of vision is generally taken as horizontal.

(*b*) *The second condition which determines the intensity of the glare is the distance away of the glare source.* A bare lamp 50 ft. away will produce little or no discomfort.

(*c*) *The last condition is the time of exposure of the eyes to the glare source.* A bare lamp for the basement or back porch where the time of exposure is short, will not be serious, but the same lamp in the kitchen will be bad.

224. Effects of Glare.—(*a*) *Temporary Lessening of Vision.* This comes from a reduction in the pupillary area and from the direct effect of the light entering the eye. It may be serious in its effects if the eye is frequently subjected to this glare condition.

(*b*) *Eye Discomfort.*—The eye tries to lessen or avoid the discomfort by turning away from the glare source.

(*c*) *Eye Fatigue and Strain.*—The most serious effect of glare comes in most cases from lights which are not so excessive in brightness or amount as to come under conditions (*a*) and (*b*) and are therefore not recognized as glare sources. These produce the greatest injury to the eyes. One fact which needs to be noted is that the final effect of eye strain is not produced at once but is due to the cumulative strains, often extending over long periods.

225. Glare Due to Reflection.—The glare due to reflection from highly polished surfaces is especially bad, since in most cases the reflections come from *below* the line of vision and the eye is least protected from such light. Glass, polished wood, and high-gloss paper are the chief sources of such reflections.

226. Types of Lighting. (*a*) *Direct Lighting.*—The light comes directly from the source to the place where used. A shade or reflector is usually used to throw the light in the useful direction. Glare by reflection from polished or glossy surfaces can be easily produced by this type and strong shadows are present when too few units are used. This type

will give high intensity on the working plane for a given candle power lamp and is therefore the most economical (see Fig. 120(*a*), Nos. 8–14).

FIG. 121(*a*).—Direct lighting.

When the sources of light are mounted high, and the separate units properly spaced and equipped with shades or reflectors of correct design, the direct-lighting type may be satisfactory.

"Luminaire" is a term used to designate a lighting unit. It includes the fixture, lamp, and shade, or reflector.

FIG. 121(*b*).—Direct lighting.

(*b*) *Semi-indirect Lighting.*—The semi-indirect unit or luminaire is defined as a lighting device employing a diffusing or translucent medium to direct most of the light to the walls or ceiling to be redirected for use. a part of the light being diffused through this medium.

The essential feature of this unit is an inverted bowl of fairly large diameter, the inside of which is polished and the

Fig. 121(c).—Semi-indirect lighting.

outside rough. The lamp is suspended in the bowl in either the horizontal or vertical position and is completely hidden. The light is partly reflected from the inside of the bowl to the

walls and ceiling, which in turn diffusely reflects it to the walls and downward. A part of the light is transmitted

FIG. 121(*d*).—Indirect lighting.

through the bowl, largely in the downward direction as directed light and to a limited degree as diffused light (see Fig. 120(*b*), Nos. 22–25).

The combination of the diffusely reflected light from the ceiling and the direct light through the bowl produces a soft, diffused light with enough variation in intensity and distribution to break up any monotony in the lighting effect. There is a danger of the bowl being too transparent or the lamp too high candle power for the bowl, in which case the direct component is too great and a bad condition of glare may result. A luminaire which transmits about 25 per cent and reflects to the ceiling about 75 per cent of the light will usually be free from glare. The cost of operation of this type is somewhat greater than for the direct type.

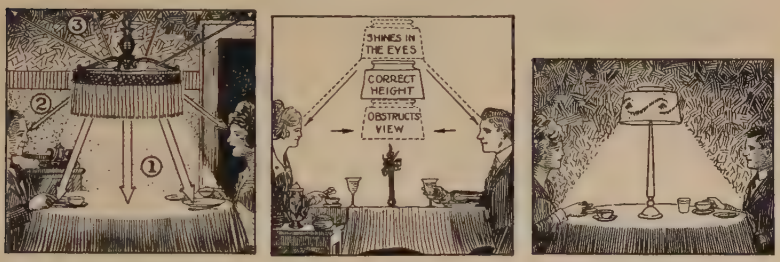


FIG. 121(*e*).—Good or bad illumination depending upon the position of the luminaire.

(*c*) *Indirect Lighting.*—In this type the luminaire directs *all* the light to the ceiling. This type gives a very soft, diffused light in the room which is not unlike daylight. There are few, if any, shadows or strong contrasts and some object to this feature. In cost of operation the indirect system is greater than the semi-indirect system. The difference in the costs of operation of the three systems, however, is not great enough to be a factor in deciding on which system to install. It will be evident that the semidirect and indirect systems both require a ceiling that is white or nearly so if absorption is not to be large (see Fig. 120(*b*), Nos. 27–28).

227. Intensity of Illumination.—The amount of illumination required differs in the home according to the use to which the room is put. No fixed values can be given and the table below must be considered as suggestive only.

Average foot-candle intensities:

Reading—ordinary print, 2 to 4 foot-candles.
Reading—fine print, 4 to 6 foot-candles.

RESIDENCE

	Foot-candles		Foot-candles
Porch	0.5	Library or den:	
Hall	1.0	General	3 to 4
Drawing room	2	Kitchen	3 to 4
Sitting room	2 to 3	Bedroom:	
Dining room:		General	1.0
General	1.00	Dressing table	4
Over table	3 to 5	Sewing room:	
		Local	6 to 12

CHAPTER XXII

REFLECTION AND ABSORPTION OF LIGHT

228. Light Incident on a Surface.—When light is incident on a surface it may be:

(*a*) Regularly reflected. Specular reflection.
(*b*) Irregularly reflected. Diffused reflection.
(*c*) Transmitted.
(*d*) Absorbed.

In general more than one of these effects is produced at the same time, but their relative magnitudes are different.

229. Regular Reflection.—The *fact* that light falling on a polished surface is reflected has been known from earliest

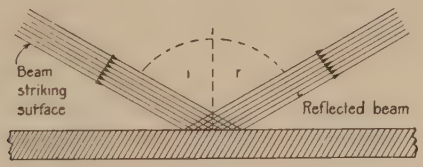


FIG. 122.—Regular or specular reflection.

times and perhaps Eve used the still surface of water as a mirror. At any rate, both metallic and glass mirrors are mentioned by the Old Testament writers of the books of Job and Exodus.

The *law* of reflection is one of the most ancient of the known laws of light. *The angle of incidence equals the angle of reflection and the two are in the same plane.*

230. Reflection and Absorption.—All polished surfaces absorb some of the light, so the intensity of the reflected light is less than that of the incident light.

Material	Percentage of light	
	Reflected	Absorbed
Highly polished silver.....	93	7
Mirror glass, silvered back....	70 to 85	15 to 30
Mirror glass, amalgam back..	60	40
Steel, highly polished.....	60	40
Gold, highly polished.....	80	20
Brass, highly polished.....	75	25
Copper, highly polished.....	70	30

231. Formation of Images by Reflection.—An image is an optical figure resembling a given object and formed by the light coming from the object.

The images produced by plane mirrors may be found by the application of the principle of the rectilinear propagation of light and the law of reflection.

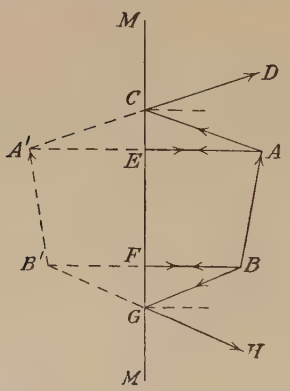


Fig. 123.—Image formation in a plane mirror.

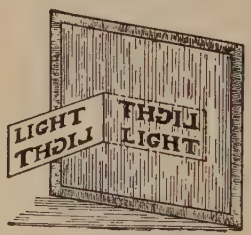


Fig. 124.—Lateral perversion.

Let AB represent an illuminated object in front of the mirror M. Then $A'B'$ represents the image as seen in the mirror. The actual path of the rays from the object to the mirror, and as reflected from it, are shown in the figure. The rays CD, EA, GH, and FB come from the mirror as if they came from A' and B' respectively. The image $A'B'$ is called a virtual image since it cannot be gotten on a screen and is not produced by rays from the same point coming together after reflection. The image is described as virtual, seemingly as

far back of the mirror as the object is in front of it, erect, the same size as the object and *perverted*. The right side of the object is seen on the left side of the image. Hold a printed page before a mirror and try to read it from the image, or try

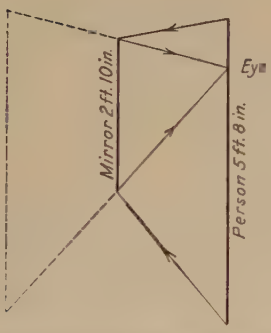


FIG. 125.—Size of object and size of mirror.

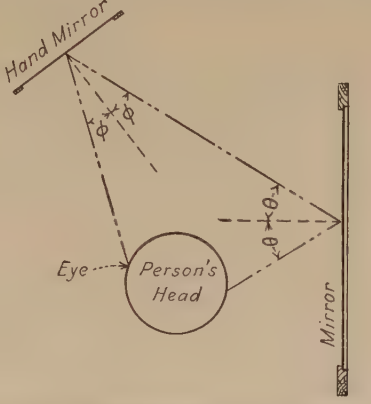


FIG. 126.—Showing use of two mirrors in dressing.

to go through the motions of tying a four-in-hand as though you were following some printed directions for doing it. The perversion of the image will be made very evident.

The illustration shows a perverted image.

The relation between the size of the mirror necessary to see the full length of an object and the size of the object is shown in Fig. 125 and in Fig. 126 the path of the light from a dressing mirror to the eye.

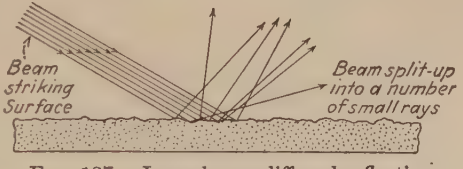


FIG. 127.—Irregular or diffused reflection.

232. Irregular Reflection. Diffused Reflection. — When the surface upon which light is incident is not highly polished, but rough or mat, the reflection is irregular, diffused, or scattered. The rays after reflection are no longer in one plane but leave the surface in all directions.

233. How We See Objects.—Few objects are self luminous, they generally reflect the light which has fallen on them.

If the surface of an opaque body could be made a perfect regular reflector, it would perfectly reflect all the light from bodies placed before it and so the images would appear as bright as the objects, *the perfect reflecting surface would be itself invisible*, and the observer would see only the reflected objects. The embarrassing and sometimes painful experiences arising from the presence of high-grade mirrors placed on the walls of a room or in halls, and the fun from the "crystal maze," illustrate well the effects of good reflectors. It would be nearly as dangerous to walk quickly across a room whose furniture was all made of perfect reflectors as to cross a busy street with one's eyes shut.

Few of the objects we use are good reflectors and their surfaces are not in parallel planes, but consist of an infinite number of little planes inclined to each other in all possible angles. They receive light and reflect it in all directions; the light is diffused, and, as a result, the object itself is seen, not the image of the source of the light. We see objects only by *diffused* light.

234. Mixture of Regular and Diffused Reflection.—While surfaces, like ceilings, walls, draperies, floor coverings, etc., produce diffused reflection almost wholly, there are many objects which have both types of reflection, differing in the amount of each. The highly polished furniture, the piano, the top of the writing desk, the page of a book, the coffee percolator, the picture on the wall are all examples of the mixture of the two types of reflectors.

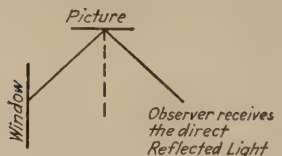


FIG. 128.—Picture obscured by direct reflected light.

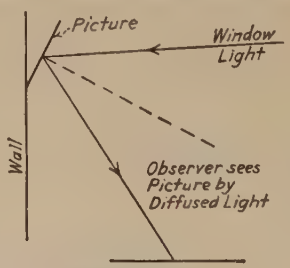


FIG. 129.—Seeing a picture by diffused light.

Pictures are frequently so placed on a wall that an observer has difficulty in seeing them distinctly. The figure shows a bad placing of a picture.

When pictures are hung above the eye on the wall, they should be so inclined that the line of sight is perpendicular to the plane of the picture.

The illustrations given below show some common examples of the mixture of the two reflections.

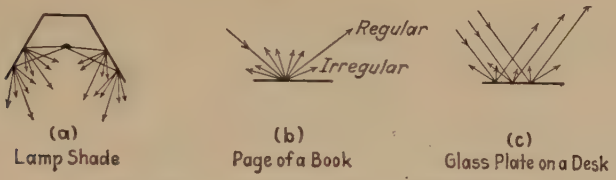


FIG. 130.—A mixture of the two reflections.

235. Absorption of Light by Surfaces.—Whenever light is incident on an opaque surface, a certain part of it is reflected and the remainder is absorbed. In the case of the silver mirror, the part absorbed is evidently 7 per cent, while for steel 40 per cent is absorbed.

Experiment shows that the factors upon which the amount of absorption depends are:

1. The condition of the surface, its color and its nature.
2. The angle of incidence the light makes with the surface.
3. The kind of light used.

The table (**Art. 230**) will, in part, illustrate the first factor. In the tables which follow, data are given to illustrate the effect of all these factors.

ABSORPTION OF SUNLIGHT BY VARIOUS SURFACES

	Percentage
Clear glass	5
White blotting paper	18
Cream paper	46
Butter	35
Newspaper	40
Yellow wall paper	60
Dark-brown wall paper	87
Dark-green wall paper	95
Deep blue	96
Navy blue cloth	98
Black velvet	99.6

Absorption at Different Angles of Incidence

	Per cent absorption at an angle of incidence of			
	60°	45°	30°	0°
Semi-gloss, light-blue paper	84.5	87	90	91.9
Rough, deep-red paper	92.7	93	94	95

236. Absorption by Different Colored Surfaces under Different Lights.

	Red walls, per cent	Green walls, per cent	Blue walls, per cent
Carbon lamp	46.6	51.4	56
Tungsten	52.8	48.9	49.6

Study Exercises

1. A bathroom, painted a blue-gray color, absorption 30 per cent, was repainted a mat white, absorption 19 per cent. What was the gain in brightness under the same lighting conditions?

2. Make a sketch showing how the rays of light reach the eye from back of the head when one stands in front of a dressing mirror.

3. Explain why a piece of plane glass is a fairly satisfactory mirror if it is backed with some dark-colored material, while the glass in the window is not so good a mirror.

4. Explain how mirrors may be used to make a room seem longer than it really is.

5. What is the relation between the size of your image in a mirror and your distance from the mirror?

6. Why are the plate-glass store windows often satisfactory mirrors?

7. Construct the image of an arrow placed before a plane mirror. What is the size of the image with respect to the size of the object?

8. Construct the image of an object 6 in. high in a plane mirror 3 in. long.

9. If the ceiling is the sole source of the reflected light from a luminaire what will be the relative intensities of the light reflected from a mat

white-papered ceiling and a cream-papered ceiling? Consult table of absorptions.

10. Show by a sketch, the minimum length of a mirror that will give an image of a person who is 5 ft. 6 in. tall.

Some Suggested Laboratory Exercises

1. Study of the light reflected by colored wall papers and woods. Munsell photometer and foot-candle meter.

REVIEW SUMMARY

Light falling on a surface may be regularly or diffusely reflected, transmitted or absorbed.

Law of regular reflection: The angle of incidence equals the angle of reflection and the two are in the same plane.

Law of diffused reflection: The angle of incidence equals the angle of reflection and the reflected rays are not in the same plane.

Images in plane mirrors, application of the law of regular reflection. The image is virtual, erect, the same size as the object, perverted and seemingly as far back of the mirror as the object is in front of the mirror.

We see objects by diffused reflection.

Absorption of light by various surfaces.

CHAPTER XXIII

REFRACTION

237. Refraction of Light.—If a pencil be placed in a dish of water and looked at from one side, the pencil will appear bent at the surface of the water.

The rays of light on passing into the water depart from the rectilinear propagation already discussed and are bent. In general, when light passes from one medium, like air, into a denser medium, like water, the rays are bent *toward* the normal, and on passing from a denser to a less dense medium, they are bent *away* from the normal.

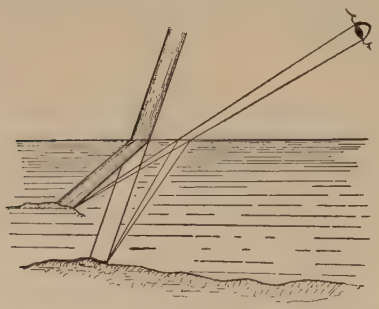


FIG. 131.—Bending of light rays.

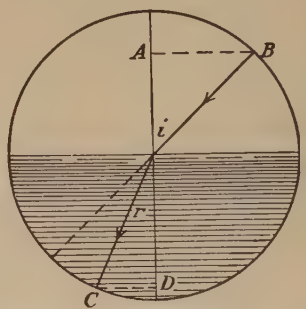


FIG. 132.—Refraction in different media.

Refraction, then, is the bending of a ray of light as it passes from one medium into another of *different* optical density.

The cause of refraction is the difference in the velocity of the light wave in the two media.

The law of refraction is that $\frac{\text{Sine } i}{\text{Sine } r}$ equals a constant, called the "index of refraction."

Angle i is the angle the light makes in the incident medium and angle r is the angle in the refracting medium. Sine i and

sine r are trigonometric terms whose values we may take as being proportional to the lengths of the lines AB and CD in Fig. 132. For air to water the ratio of $\frac{\text{Sine } i}{\text{Sine } r} = 1.33$. The index of refraction of water is then 1.33. Each substance has an index which is characteristic of the substance.

238. Lenses.—A lens is a piece of glass with polished surfaces which are spherical, cylindrical or prismatic. Spherical lenses are used in the camera, the projection lantern, and the opera glass. All three kinds are used in eye glasses.

Spherical lenses are generally concave or convex. The light is refracted in passing through them and the various effects produced result from these refractions.

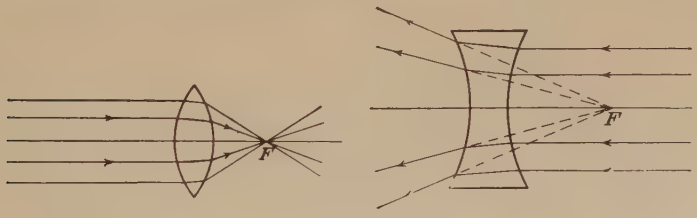


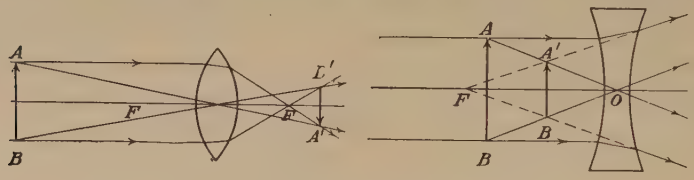
FIG. 133.—Effect of convex and concave lenses on light.

In general, the effect of a convex lens is to cause the light *to converge after refraction* and that of a concave lens is to cause the light *to diverge.*

If the light entering the lens is parallel to the axis as in (*a*) and (*b*), it comes to a point on the axis *after* refraction, called the "principal focus" F. In (*b*) since the light diverges after passing through the lens, the principal focus is found by projecting the rays backward until they meet. This focus is called a "virtual focus."

239. Formation of Images.—If AB represents an object, the image formed by the refracted light is shown at $A'B'$. In the case of the convex lens the image is real and may be thrown on a screen, while in the concave lens the image is virtual and can be seen only by *looking into the lens from the side opposite to that of the object.*

The method of finding the image in a lens is as follows: Trace two rays from any point on an object through the lens to their intersection. We have then the position of the corresponding point of the image. The easiest way to trace the two rays *through* the lens is to take one ray from the point of the object, parallel to the axis; this ray will go through the principal focus of the lens; the second ray may be taken to pass through the optical center of the lens and it will be undeviated. The images in the figures, it will be noted, were found in this way.



(*a*) (*b*)

FIG. 134.—Image formation.

240. The Lens Formula.—The position and size of the image produced by a given lens may be obtained from the relations:

$$\frac{1}{\text{image distance}} = \frac{1}{\text{object distance}} + \frac{1}{\text{focal length}},$$

and

$$\frac{\text{length of object}}{\text{length of image}} = \frac{\text{object distance}}{\text{image distance}}.$$

241. Interpretation of the Lens Formula.—By convention, positions on the side of the lens which receives the light are called "positive" and positions on the opposite side are called "negative." For a *convex* lens the focal length is always considered negative in the lens formula, and the image position negative except for the one case when the object is between the focus and the lens. For a concave lens the focal length is positive and the image position is also positive.

Illustrative Problems

(Note that in solving lens problems, we assume that the sign as well as the numerical position of the unknown is to be determined.)

1. Find the position of the image in a convex lens of focal length 10 cm., the object being 40 cm. from the lens.

From the lens formula

$$\frac{1}{ID} = \frac{1}{OD} + \frac{1}{F},$$

we have by convention:

$$\frac{1}{ID} = \frac{1}{40} - \frac{1}{10},$$

the negative sign being given to F since we have a convex lens.

Clearing of fractions:

$$400 = 10ID - 40ID.$$
$$-30ID = 400.$$

Hence

$$-ID = 13\tfrac{1}{3} \text{ cm.}$$

The minus sign shows that the image is on the opposite side of the lens from the object.

2. Find the focal length of a convex lens which forms a real image 30 cm. from the lens when the object is 20 cm. from the lens.

$$-\frac{1}{30} = \frac{1}{20} + \frac{1}{F}.$$
$$-20F = 30F + 600.$$
$$-50F = 600.$$
$$-F = 12 \text{ cm.}$$

Again the $-F$ informs us that the focus is on the opposite side of the lens from the object.

3. A lens of focal length 10 in. forms a real image 30 in. from the lens. What is the position of the object?

$$-\frac{1}{30} = \frac{1}{OD} - \frac{1}{10}.$$
$$-10OD = 300 - 30OD.$$
$$20OD = 300.$$
$$+OD = 15.$$

The object is on the positive side of the lens.

4. A convex lens of focal length 20 cm. has an object 10 cm. from the lens. Where is the image?

Using the convention for signs, we have

$$\frac{1}{ID} = \frac{1}{10} - \frac{1}{20}.$$
$$200 = 20ID - 10ID.$$
$$10ID = 200.$$
$$+ID = 20 \text{ cm.}$$

The image is on the same side of the lens as the object.

5. A concave lens of focal length 10 cm. has an object 40 cm. from the lens. Where is the image?

Using our convention as to the signs, we have

$$\frac{1}{ID} = \frac{1}{40} + \frac{1}{10}.$$

$$400 = 10ID + 40ID.$$

$$50\text{ID} = 400.$$

$$+ID = 8 \text{ cm}.$$

The positive sign shows the image is on the same side of the lens as the object.

6. The fixed-focus hand camera is seemingly a direct violation of the lens formula as the distance of the film from the lens, the image distance, is constant and the object distance may be variable.

In a given fixed-focus camera, the focal length of the lens was 3.5 in. and the distance from lens to film was 3.6 in. From the lens formula, the object being 120 in. away from the lens, we find:

$$\frac{1}{ID} = \frac{1}{120} - \frac{1}{3.5},$$

or

$$-ID = 3.605 \text{ in.}$$

For an object 240 in. distant, we have

$$\frac{1}{ID} = \frac{1}{240} - \frac{1}{3.5}$$

or

$$-ID = 3.551 \text{ in.}$$

If the eye cannot detect any difference in the sharpness of the photographic image which in one case was in sharp focus 0.005 in. farther away from the lens than the film and in the second case was in sharp focus 0.049 in. in front of the film, then a fixed-focus camera will be satisfactory.

In general fixed-focus cameras give satisfactory images for objects 10 ft. or more from the camera.

7. What is the size of the image in Problem (4) if the object is 25 cm. high?

$$\frac{OD}{ID} = \frac{OS}{IS}.$$

$$\frac{10}{20} = \frac{25}{IS}, \; IS = 50 \text{ cm}.$$

242. General Description of Images. (*a*) *Double Convex Lens.*

1. Object distant more than twice the focal length of the lens. The image is less than twice the focal length and more than once the focal length from the lens, it is inverted, real, smaller than the object, and on opposite side of the lens.

2. Object $2F$ distant. The image is $2F$ away, inverted, real, the same size as the object and on opposite side of the lens.

3. Object less than $2F$ and more than F distant. The image is more than $2F$ distant, larger, inverted, real, and on opposite side of the lens.

4. Object less than F distant. The image is erect, virtual, and its size and position depend upon the position of the object.

(*b*) *Double Concave Lens.*

1. Whatever the position of the object, the image is always erect, virtual, smaller, and on the same side as the object.

The student should by use of the formula test the position and size relations given above and by a graphical solution test all the relations.

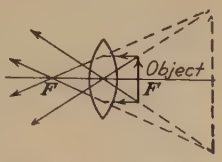


FIG. 135.—Reading glass or small magnifyer.

Study Exercises

1. A beam of light strikes a water surface at an angle of 45 deg., and the refracted beam makes an angle of 32 deg. What is the index of refraction of water?

2. If the index of refraction of the glass in a spectacle lens is 1.52, what is the angle of refraction if the angle of incidence is 30 deg.

3. By construction, show that a bundle of parallel rays passing through a double convex lens converge to a point.

4. By construction, find the effect of a concave lens on parallel rays.

5. The image of an object is 6 in. from the lens in a given hand camera. How far away is the object, the focal length of the camera lens being 4 in.? What are the relative sizes of the object and the image?

6. A reading glass of focal length 3 in. is held 2 in. from the printed page. Where is the image? Describe it.

7. Construct the image of an object 200 cm. away from a convex lens of focal length 20 cm. Describe the image and locate it in terms of the focal length. Case of the camera.

8. If a picture of a woman 5 ft. tall is taken with the above camera, the woman being 20 ft. from the camera, find the size of her image in the picture.

9. By construction, find the image in a double convex lens, focal length 4 in., of an object 1 in. from the lens. Case of the hand magnifier or reading glass.

10. In a projection lantern the object is $\frac{3}{4}$ ft. from the lens and is $\frac{1}{4}$ ft. tall, the screen is 20 ft. distant. How high is the image?

11. What is the magnifying power of a hand magnifyer whose focal length is 1 in. and the object is $\frac{1}{2}$ in. from the lens? The ratio of image size to object size is the magnifying power.

12. In a fixed-focus camera, the film is 4.1 in. from the lens whose focal length is 4 in. A picture was taken of a person 300 in. from the camera and of a house, which served as a background, which was 400 in. from the camera. How far from the film surface were the actual images in sharp focus?

243. Defects of Images.—In Figure 136 the image $A'B'$ is assumed to be a straight line, but it can be seen that the point A is at a greater distance from the center of the lens than the point B and the lens formula shows that A' must also be a greater distance from the lens than B'. In other words, the image $A'B'$ is curved, not straight.

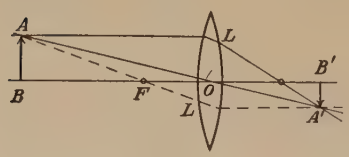


Fig. 136.

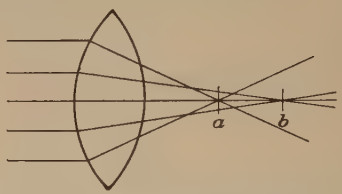


Fig. 137.—Spherical aberration. Focus at an area greatly exaggerated.

If, in the camera, a simple lens is used and the picture is sharply focused for the center portion, the edges must be a little out of focus, they will be fuzzy. A large object close to the lens, portrait work, will show this defect especially well. The cheap hand camera, while giving good distant views, produces an unpleasant likeness of a friend if the picture is taken too close. This defect is known as "spherical aberration."

In the figure the rays coming from the central portion of the lens tend to focus at b while those coming from the outer portions tend to focus at a. The focus which ought to be a point is an area; the image is not sharp. The use of the diaphragm or stop cuts out some of the rays coming from the edges of the lens and helps to make the image sharper. But the *brightness* is decreased and a *longer exposure* is necessary.

If white light passes through a lens, it is found that the light is no longer white but is broken up into the colors of the spectrum. The effect of the lens was to decompose the white light into its elements. Each color came to a focus at a

different distance from the lens, the violet being nearest and the red farthest away. When a single lens forms an image of an object, the image is bordered with colors which tend to make it less distinct. This defect is known as "chromatic aberration."

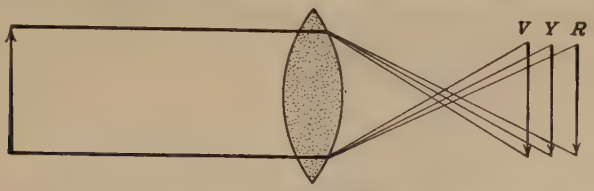


FIG. 138.—Chromatic aberration. Different focus for red and violet rays, greatly exaggerated.

In practice then, to eliminate these two defects, combinations of lenses, with or without a diaphragm, are used in place of the simple lens and these are so designed that the imperfections of one lens are balanced by the opposite imperfections

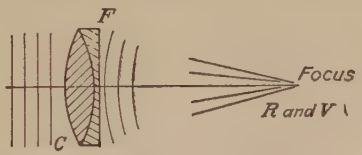


FIG. 139.—Achromatic lens.

of another lens. Such a system of lenses is known as an "achromatic" lens.

244. The Opera Glass.—The opera glass consists of a convex lens as the objective, and a double concave lens as the eyepiece. The optical system is shown in the figure.

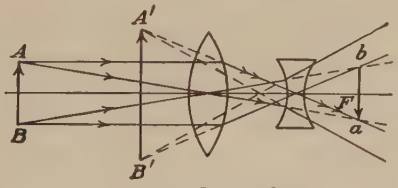


FIG. 140.—Opera glass.

If the concave lens were absent, the objective lens would form a small, inverted real image i at ab. The effect of the eye piece is to form a virtual, erect image i, at $A'B'$, and it is

this enlarged image that the eye sees. The field of view of the opera glass is small, so it is usually made to magnify three or four times. A field glass is a large-sized opera glass. The prism type gives the larger field of view desired and at the same time keeps the size small by using prisms to give the longer path for the light necessary if a longer focus objective is to be used. The illustration shows such a combination of lenses and prisms.

If the lens system (Fig. 141) was used without the prism system, the opera glass would be three times longer.

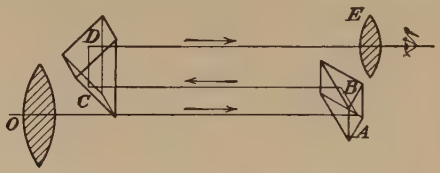


Fig. 141.—Prism binocular.

245. Visual Judgments.—The eye and the camera are frequently compared as optical instruments because of the likeness of the optical principles. But the impressions received from the eye are very much unlike those received from a photograph. A photograph gives a picture of an object in a fixed position, while the eye gives to the brain a very complex picture. The difference between the single impression from a photograph and the complex impression from the eye can be illustrated by comparison of the impressions received from a snapshot of a child at play with those received from a moving picture of the child, where several simultaneous impressions are received. The camera picture gives us definite judgments of the position, size, and form of objects, whereas the images formed by the eye are interpreted in the light of our past experiences and judgments. The apparent converging of the rails on a railroad when we look along the track for a distance must be interpreted in view of our past experience with railroads.

246. Optical Illusions.—The fact that we always *interpret* the images we receive on the retina makes it possible to be deceived through the sense of sight.

The white square looks larger than the black one. A person dressed in white will look larger than when dressed in black.

If the two sets of lines below are looked at the horizontal set looks higher than it is wide, while the vertical set looks wider

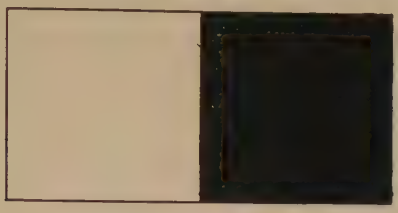


Fig. 142.

than it is high. The two sets, are, as a matter of fact, equal squares. Stout people who wear clothes with horizontal stripes and slim people who wear clothes having vertical stripes

Fig. 143.

both increase their faults. Rooms may have their impressions of size changed by the character of the wall paper or the paneling.

THE EYE

247. Results of Eye Defects.—To see clearly, when the eyes are defective requires a constant physical effort and results in the expenditure of a large amount of physical energy and nerve force.

Headaches, mental exhaustion, neuralgia, and other ills are sometimes due to the eyes.

The remedy is frequently found in properly adjusted glasses.

248. The Optical System of the Eye.—The crystalline lens is the most important part of the optical system. It is in

effect a double convex lens of index of refraction 1.437 and it focuses the light rays on the retina. In order that the eye may see near or distant objects sharply, the crystalline lens is capable of having its curvature changed by the action of the eye muscles. When they are relaxed, the lens become thicker and has its focus shortened and when they are tightened the lens is drawn out into a thinner lens, thus lengthening its focus.

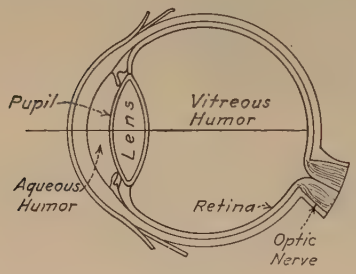


FIG. 144.

As old age comes on, the crystalline lens becomes harder and so can not adjust itself for near and far objects. The remedy is two kinds of glasses or both kinds in one, the bifocal, one of which helps the eye to focus on near objects and the other for far objects.

249. Far and Near Sightedness.—Sometimes the eyeball is too flat or too elongated to bring the light to a focus on the retina. If the eyeball is flattened, the light is brought to a focus beyond the retina and the eye muscles must cause the crystalline lens to become thicker, so as to decrease its focal length. Such eyes are far sighted or the eyes are hypermetropic.

If the eyeball is too elongated, the light is brought to a focus in front of the retina and the eye muscles must contract to make the crystalline lens thinner or of longer focus. Such eyes are near sighted or myopic.

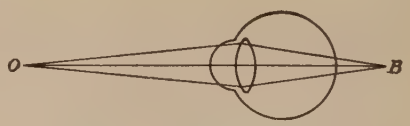


FIG. 145.—Hypermetropic eye.

To relieve the eye muscles from the severe tension necessary to overcome the defects of far or near sightedness, artificial lenses must be placed in front of the eyes. If the person is far sighted a convex lens is used of such a curvature or focal length that its effect added to the natural effect of the crystalline lens will bring the light to a focus *on* the retina, while the myopic eye requires a concave lens.

The ability of the eye to focus distant and near objects by changing the curvature of the lens is called "accommodation." The accommodation decreases with age, and the loss, whole or partial, of the accommodative ability is called "presbyopia." Such eyes require the use of spectacles of different focal lengths for focusing on near and far objects. The "bifocals" are used for this defect.

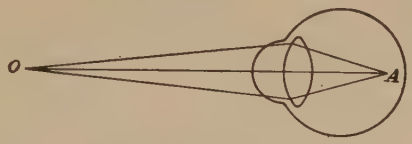


FIG. 146.—Myopic eye.

250. Spectacle Lenses.—Oculists use the term "diopter" to measure the strength or power of eyeglass lenses. By convention the power of the lens is expressed by the relation:

$$\text{Power} = \frac{100}{\text{focal length in centimeters}}.$$

A lens of focal length 100 cm. is said to have a strength or power of 1 diopter. A lens of 40 cm. focal length has a strengh of 2.5 diopters. If the lens is convex, converging the light, its strength is given as +diopters and if the lens is concave, diverging the light, its strength is given as −diopters.

In the case of an astigmatic eye, the angles made by the meridians of greatest and least curvature with the horizontal give the position of the astigmatism. The angles are measured counter-clockwise from the right-hand horizontal line through the eye as seen by a person looking toward the eye.

An oculist's prescription for defective eyes might read:

$$\begin{matrix}\text{O.D.} + 0.6\text{D sph.} \\ \text{O.S.} - 1.5\text{D sph.}\end{matrix} \qquad (1)$$

or

$$\begin{matrix}\text{O.D.} + 3\text{D cyl. ax } 45° \\ \text{O.S.} - 1.5 \text{ cyl. ax } 135°\end{matrix} \qquad (2)$$

When interpreted, (1) means that the right eye, O.D. (ocular dexter) is to have a convex spherical lens of $\frac{6}{10}$ diopter strength, or a focal length of 166 cm., while the left eye, O.S. (ocular sinister) requires a concave spherical lens of 1.5 diopters,

or 66 cm. focal length. Prescription (2) means the eyes are to be fitted with positive cylindrical lens of the indicated strength, but the axis of the cylindrical lens for the right eye is at 45 deg. to the horizontal and for the left eye it is 135 deg. to the horizontal.

251. Snellen Test Chart.—Place the test page 20 ft. away from the person. Have it well illuminated but do not allow any of the light to enter the eyes directly. Test each eye separately, using a black cover for the other eye. If the person can read the letters marked 15 ft. at a distance of 20 ft., that person is far sighted. If a person cannot read the letters on the 20-ft. line, he is near sighted. The degree of near sightedness is indicated by the line he can read. If the test indicates near sightedness the eye specialist should be consulted at once (Fig. 147).

Illustrative Problems

1. For near-sighted eyes.—The oculist uses a concave lens in front of the eye of such a focal length that when an object is 25 cm. from the eye, its virtual image is at the *nearest* distance for distinct vision for the eye being tested. Let us assume this distance is 12.5 cm. Then from the lens formula,

$$\frac{1}{12.5} = \frac{1}{25} + \frac{1}{F}; \text{ hence } F \text{ equals } 25 \text{ cm.}$$

and its strength would be given as $-4D$.

2. For far-sighted eyes.—A convex lens is placed before the eye, of such a focal length that an object 25 cm. from the eye will have its virtual image at the nearest distance for distinct vision for the eye tested. Assume this distance is found to be 37.5 cm., then as before,

$$\frac{1}{37.5} = \frac{1}{25} + \frac{1}{F}; \text{ hence } F = -75 \text{ cm.}$$

and its strength would be given as $+1.3D$.

252. Astigmatism.—This defect is caused by the lens or cornea being unsymmetrical, there being a different curvature in one or more of the planes. Any image produced is distorted, like your face in a teaspoon.

Test for Astigmatism.[1]—Hold the page containing the test chart 2 or 3 ft. away. Astigmatism is present if some of the

[1] The experiments suggested under the Snellen test and for astigmatism are not intended to replace the services of an oculist.

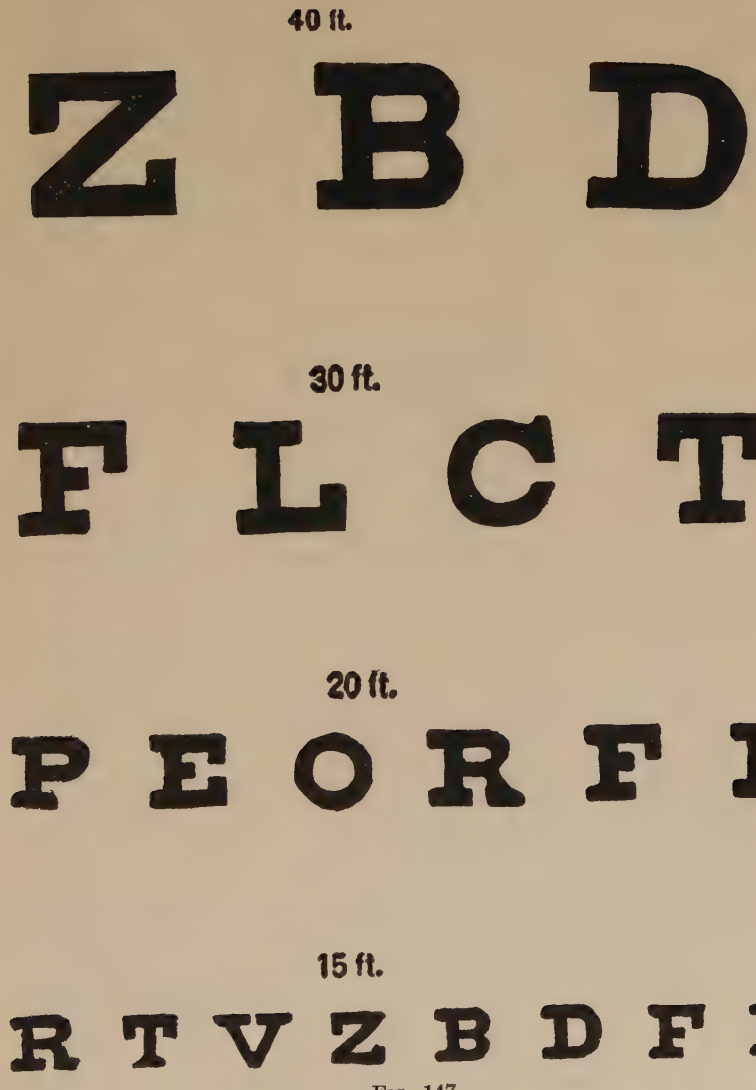


FIG. 147.

lines in the chart appear brighter and more distinct than others.

Why Two Eyes.—Some years ago nearly every home had a stereoscope with its accompanying collection of pictures of famous places and events. The pictures were always double, each taken from two slightly different positions corresponding to the eyes. When viewed through the double lens of the stereoscope, the pictures stood out in three dimensions. They appeared as solid, not flat, objects.

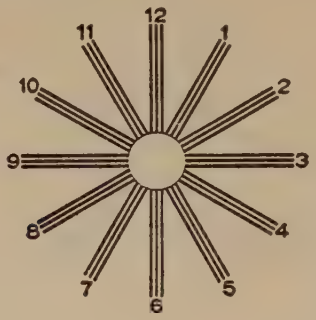


Fig. 148.

If one closes one eye and tries to thread a needle, it is almost impossible to do it. But with both eyes the needle stands out as a solid and we have little difficulty in threading it.

The two images of an object formed by the two eyes from slightly different positions blend into one sensation and we get the effect of solidity, which makes the object stand forth free from the background.

Try holding your hand at arm's length and looking at it first with one eye closed and then with the other closed. You will notice that your hand seems to be against the wall of the room and also that it appears to each eye to be in a different position against the wall. Looking with both eyes, the hand at once comes out from the wall and appears as a solid.

Some Suggested Laboratory Exercises

1. Determination of the focal length of a convex lens.
2. Study of the images formed by convex and concave lenses when the object is at different positions.

3. Experimental study of an opera glass with and without a prism system.

4. Experimental study of the sharpness of the image in a camera with varying sized stops.

5. Test of individual eyes with the Snellen and the astigmatism charts.

REVIEW SUMMARY

Refraction, the bending of the light as it passes from one medium into another of a different density.

Law of refraction, sine i/sine r equals a constant equals index of refraction.

Cause of refraction—a difference in the velocity of light in the two media.

Lenses—concave, diverging effect on light, convex, converging effect.

Images are formed due to the refraction.

Lens formula $\frac{1}{ID} = \frac{1}{OD} + \frac{1}{F}$.

For a convex lens ID and F are in general negative; that is, they are on the opposite side of the lens from the object.

For a concave lens ID and F are positive; that is, they are on the same side of the lens as the object.

Defects of a lens: (*a*) spherical aberration due to light which comes up to the entire face of the lens, converging to different points on the principal axis; (*b*) chromatic aberration, due to white light passing through the lens at any point producing colored foci at different points on the principal axis.

Spherical aberration lessened by stopping down the diameter of the lens.

Chromatic aberration overcome by combining a convex and a concave lens of different glass and different focal lengths—the achromatic lens.

Opera glass, combination of a double convex lens as objective and a concave lens as eyepiece. The image is enlarged, erect and virtual.

Prism glass, decreases the length of the opera glass for a given lens system.

Eye, the crystalline lens the most important part. Changes its focal length by changing the curvature of the lens.

Eye defects are mainly nearsightedness, farsightedness, and astigmatism.

The far-sighted eye requires a double convex lens to cause the light to converge more.

The near-sighted eye requires a double concave lens to cause the light to diverge more.

Diopter, the strength of a spectacle lens expressed as $100/F$ in centimeters.

Snell's chart, a device for testing for near or far sightedness.

Astigmatism, a defect due to the eye's inability to focus sharply on objects in different planes.

CHAPTER XXIV

PRODUCTION OF COLOR

253. Color Defined.—The term "color" is employed in three different senses. It may refer to the sensation, sometimes to the cause of the sensation, and again to pigments or paints. The word "hue" is correctly used to denote the cause of the sensation. Hue is a definite quality determined by the frequency or combination of frequencies of the light coming to the eye. A given color sensation may be produced by very different combinations of hues. If we mix, for example, red and green lights, the sensation they produce cannot be distinguished from a monochromatic yellow light. We shall see presently that the sensation of white may be produced by several different combinations of hues.

254. Methods of Producing Color from White Light (Sunlight).—Colors may be produced from sunlight by means of:

1. A prism of glass. Dispersion.
2. A diffraction grating. Diffraction.
3. Thin films. Interference.
4. Action of colored bodies. Reflection and absorption.

255. The Prism Method.—When a beam of white light is passed through a prism, it is bent or refracted by different amounts and a band of colored light is produced. Newton divided this colored band or spectrum into seven divisions, red, orange, yellow, green, blue, indigo and violet. By other means it may be shown that this colored band is due to a multitude of light waves of many different frequencies or wave lengths. It is very roughly similar to the musical scale made up of sound waves of varying frequencies, pitch, or wave lengths. These light waves range in wave length from about 0.00075 mm. in the red to 0.00035 mm. in the violet, and in vibration rate or frequency from 39×10^{13} per second for the red to 85×10^{13}

for the violet. Just as the ear hears the note called middle C when a string on the piano vibrating 256 times per second is struck, so the eye sees the red when it receives 39×10^{13} vibrations per second. Outside of our sensations color does not exist and is, therefore, entirely subjective. The objective part is whatever excites the retina, and this is usually light waves of different frequencies.

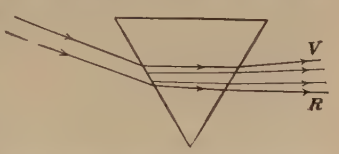


FIG. 149.—Effect of a prism on a beam of light.

We may assign the various colors (hues) to the following approximate ranges of wave lengths:

	Wave Lengths, Millimeters
Red	0.0007 to 0.000620
Orange	0.000620 to 0.000592
Yellow	0.000592 to 0.000578
Green	0.000578 to 0.000513
Blue	0.000513 to 0.000464
Violet	0.000464 to 0.000397

256. White Light and Colored Light.—Sunlight, then, is complex, as it is composed of innumerable waves of different lengths or frequencies; and white light from other sources will be found to be complex, too, although it may differ greatly in its complexity. For example, if red, green, and blue lights are combined by being thrown on the same spot on a screen, the result is white light. Colored light, too, may be simple or complex in its composition. We may cut a very narrow slit in the screen on which the spectrum was produced and let the yellow bundle of colored rays, for example, fall on a second prism. The result is a *yellow* band of light only, bent but otherwise unchanged. The yellow light was evidently simple in character, not complex. On the other hand, we may throw on the same spot on the screen the red and green light from the spectrum and obtain a yellow which looks exactly like the original spectrum yellow.

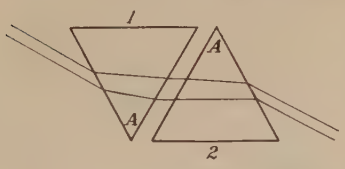


FIG. 150.—Synthesis of light.

Newton found that a second prism, similar to the first, but inverted as shown, recombined the several spectrum colors into white light. The same result may be obtained by superimposing the separate spectrum colors on each other on a screen. These results also show the complexity of white light.

257. Effect of Colored Bodies. Reflection and Transmission.—We will now study the cause of colored bodies. All colored bodies are seen by the light which has been transmitted through them or reflected from them. We will consider first the colors produced by transmission.

Transmitted Colors.—Let white light pass through a piece of so-called red or green glass. It is evident at once that the glass has had some effect on the white light and that the resulting redness or greenness of the light coming to the eye is due to the glass. What did the glass do? We may easily get an answer by projecting on the screen the spectrum of white light by means of a prism or grating and placing the red glass in front of the prism or grating. We note at once that the effect of the red glass is to cut out certain of the colors present in the white light, but not, perhaps, the colors we might have expected: that is, all except the red. The glass has transmitted other colors besides the red. The red light, then, coming to our eye is not the simple red of the spectrum but a complex red made up of several different colors, with different amounts of each. A similar effect results with the green glass. We may represent graphically the result from one particular red glass as follows:

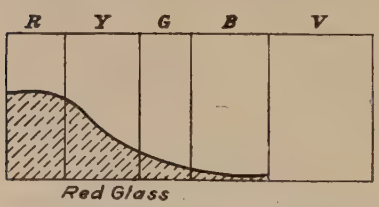


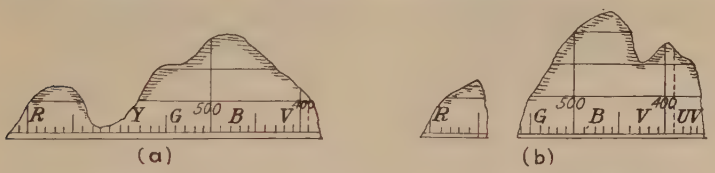
FIG. 151.—Absorption and transmission of a red glass for white light.

The large rectangle in Fig. 151 represents the full spectrum; the shaded portion shows the colors *transmitted;* and the heights of the vertical lines in the shaded portion indicate the relative intensities of the colored lights transmitted. If two thicknesses of the red glass are used, we may find that all the blue light is now absorbed and the intensities of the remaining

colors changed, and a further increase in the amount of red glass may result in a transmission of the red light only. In all three cases the resulting light is red, but a slightly different red in each case.

The red color of the glass was due to the transmission by the glass of those elements in the white light and in the relative amounts, shown by the shaded area. We may say also that the red color of the glass was due to the elements of white light which were absorbed by the glass, represented in the figure by the unshaded portion.

Let the light from a sodium flame, which is a pure yellow, pass through the red glass. The result is a weak yellow color, not red at all. This result easily could have been predicted from the absorption and transmission curve for the red glass.



Diamond green. Malachite green.

FIG. 152.

The spectrograph above shows in the heights of the vertical part of the curves, the amount of light of the various colors or wave lengths transmitted by two green dyes, (*a*) diamond green, (*b*) malachite green. The malachite green is a blue-green and the spectrograph shows this in the greater amount of the blue transmitted.

The color of an object which transmits light depends upon two factors: (1) the colored elements of white light which it transmits, and (2) the kind of light which falls on the object. What would be the color of the light transmitted through the malachite green if orange-hue spectrum light illuminated the dye?

258. Color by Reflection. Opaque Objects.—Let us examine the color of a certain wool which was dyed with naphthol yellow and indigo extract. It will be simplest to use the same method that was used in the study of transparent

objects. A gelatin film, stained with the naphthol yellow, a yellow stain, shows an absorption and transmission spectrum represented by the upper diagram (1), while the indigo extract spectrum is represented directly below (2). The third part

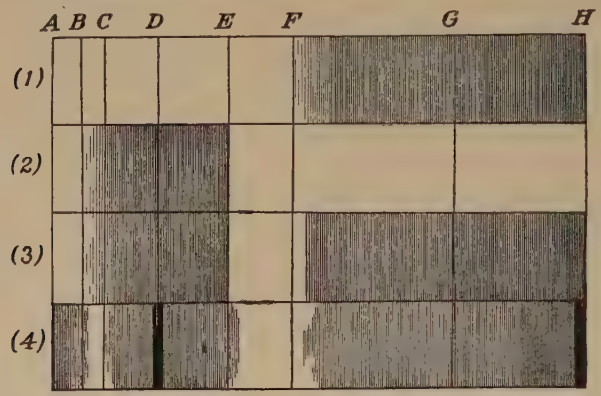


Fig. 153.—Absorption and transmission of two different greens.

of the diagram (3) shows the result of superimposing the two films and accounts for the resulting green in the dyed wool.

In the illustration above, the shaded portions represent *absorption* of light and the clear portions transmission. The letters at the top refer to the Fraunhofer lines; that is, to definite wave lengths in the spectrum. The *A* and *B* lines are in the red, the *C* line in the orange, the *D* line in the yellow, the *E* line in the green, the *F* line in the blue and the *G* and *H* lines in the near and far violet.

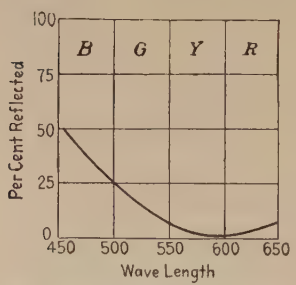


Fig. 154.—Reflection of ultramarine blue.

The green thus produced is composed of the extreme red, the green and the blue-green of the spectrum and, of course, cannot be a pure green.

The last diagram (4) representing the green produced by combining picric acid and indigo extract, shows it is composed of the red between the (*B*) and (*C*) lines, the green, blue-green

and a little of the blue. This green would be called a yellowish-green. Had white light been incident on the wool, the colors which it did not absorb and therefore reflected, would have been those which were transmitted by the two gelatin films. The color of opague objects is due to the colored elements of white light which they do not absorb.

Figure 154 shows another way of analyzing a given color, in this case ultramarine blue. It shows clearly that this blue is due to the mixture of four hues in different amounts, with the blue reflected light greatly in excess.

259. Color Constants.—The art and science of color suffer greatly from a lack of standardization of the terms used in describing the quality of colors and from having no satisfactory system of color notation. Munsell in his book on "Color Notations" quotes from a letter by Robert Louis Stevenson, who was at Samoa and was writing to a friend in London:

> Perhaps in the same way it might amuse you to send us any pattern of wall paper that might strike you as cheap, pretty and suitable for a room in a hot and extremely bright climate. It should be borne in mind that our climate can be extremely dark, too. Our sitting room is to be in varnished wood. The room I have particularly in mind is a sort of bed and sitting room, pretty large, lit on three sides, and the colour in favour of its proprietor at present is a topazy yellow. But then with what color to relieve it? For a little workroom of my own at the back, I should rather like to see some patterns of unglossy—well, I'll be hanged if I can describe this red—it's not Turkish and it's not Roman and it's not Indian, but it seems to partake of the last two and yet it can't be either of them because it ought to be able to go with vermillion. Ah, what a tangled web we weave,—anyway, with what brains you have left, choose me and send some—many—patterns of this exact shade."

Even this master of descriptive language could not describe the colors wanted. A universal color notation is badly needed to replace the inexact and unscientific now used. Luckiesh says: "We have rose, Indian red, Alice blue, pea green, olive green, cerise, taupe, baby blue, Copenhagen blue, king's blue, royal purple, etc. Thus flowers, vegetables, cities,

the savage, and the royal family are used to describe colors. Is there a more ridiculous instance of neglect?

Colors may be described in a number of different ways. One method is to name the hue, the purity and the brightness of the color. These terms will be defined and their use in describing a color illustrated in the articles which follow. A second method of defining a color will be discussed in a later chapter.

260. Hue.—We name the hue of a color by selecting the nearest spectrum color as red, yellow, blue. The dominant hue is more accurately specified by locating it in the spectrum by its wave length.

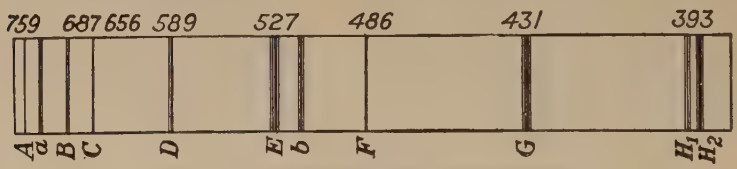


FIG. 155.—Spectrum scale in wave length.

The letters, *A*, *B*, *C* refer to the Fraunhofer lines. They represent definite wave lengths in the spectrum whose values in whole numbers are given at the top of the figure. For example, the *D* Fraunhofer line has a wave length of 0.000589 mm. and lies in the edge of the yellow.

We can then state the hue of a color by saying it is near wave length 600. But the colors we observe are not pure colors. They are made up of a mixture of several groups of wave lengths. In the case of the color of the red glass, it was found to be a mixture of wave lengths, and so not exactly like the pure red of the spectrum. Its hue would be called red, as the position of the dominating color is in the red end of the spectrum.

261. Purity, Saturation or Chroma.—The only pure colors are the spectrum colors, and we say their purity is 100 per cent. A mixture of white light or any other color with a given color produces an impure color or one whose purity is less than 100 per cent. To match any impure color of a given dominant hue, white light is added to the spectrum color of the same dominant hue, until the two look alike. The percentage of

the pure spectrum color in the mixture gives the purity of the matched color. The terms "saturation" and "chroma" have the same meaning as purity.

262. Luminosity—Brightness—Value.—The brightness of a color refers to the amount of light it reflects to the eye. A *white* surface is the most luminous or bright and a *black* surface the least bright. Brightness is frequently given as percentage of reflected light compared with the reflection from a standard white surface taken as 100 per cent.

Pure colors are not necessarily bright or luminous. The brightness or luminosity curve shows that the colors at the ends of the spectrum are not bright.

Many impure colors appear very luminous. Naphthol yellow, for example, appears very bright.

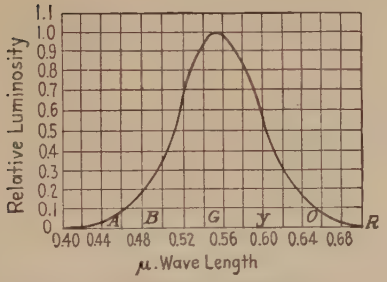


FIG. 156.—Brightness or luminosity curve.

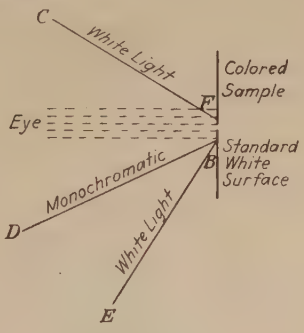


FIG. 157.

263. Monochromatic Analyzer.—To illustrate the monochromatic analysis of a color, a simple device will be described. The eye sees two fields side by side, field F, the colored sample, to be analyzed, and field B, the standard white. The beam D of monochromatic light is of the same wave length as the dominant hue of the colored sample, and is thrown on the field B. White light from E is thrown on the field B, its amount being adjusted until the field B matches field F. The percentage of monochromatic light in field B gives the purity of the colored sample. The brightness is determined by the amount of light reflected from the colored sample compared with the amount reflected from the standard white field.

To illustrate the analysis of a color by the three factors of hue, purity, and brightness, some data by Nutting and Abney are given:

Material	Hue wave length	Purity	Brightness percentage of reflection
Nutting:			
Dandelion	580	91	
Chocolate	595	30	5
Butter—light	580	55	
Navy blue (U. S.)	472	10	1.9
Abney:			
Vermillion	610	97.5	14.8
Chrome yellow	583	74	78
Cobalt blue	482	45	14.5

264. Tones, Tints, and Shades.—Three other descriptive color terms need to be defined. Tone refers to differences in

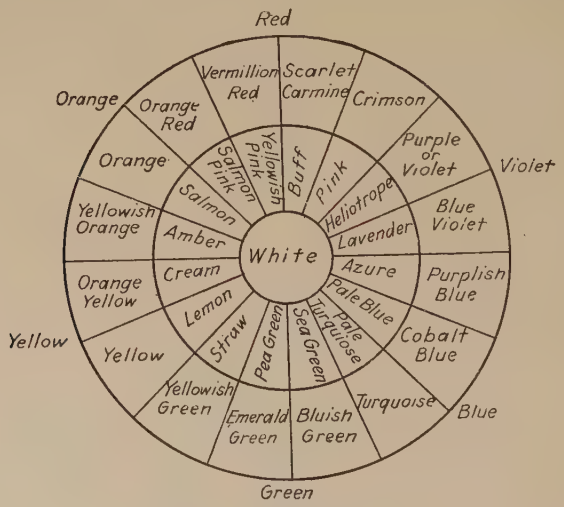


FIG. 158.—Production of tints.

colors all of the same hue, and includes tints and shades. Tints are produced by adding white to a hue and shades are mixtures of a hue with black.

The inner circle (Fig. 158) represents the effects of adding white to the saturated hues in the outer circle and Fig. 159 represents the effects of adding black. These figures are taken from "Textile Color Mixing," by David Paterson.

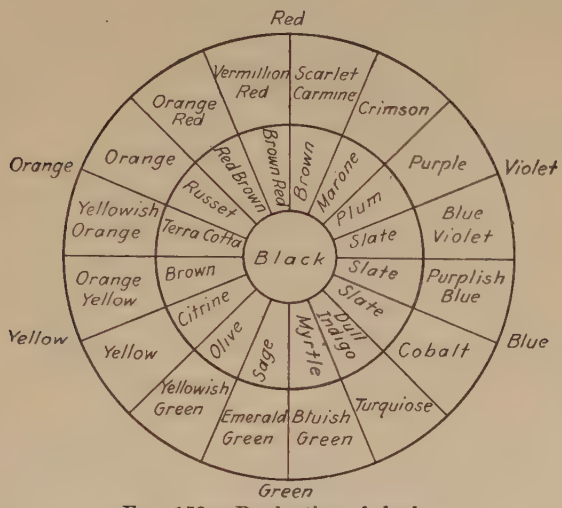


FIG. 159.—Production of shades.

265. Hue Differences.—If we examine the absorption spectra of plates with vermilion, carmine, and Indian red, as was done with the red glass, Fig. 160 shows the result.

In each case we have a hue situated in the red, but the carmine has more of the crimson than the vermilion with its bright scarlet, and the Indian red is a duller red than the vermilion. The dominant hue is slightly different in each case. The difference in these three reds would be definitely described by giving the values for the three constants of each: the hue, the purity, and the brightness.

266. Interference.—Interference phenomena are rather complex and we shall discuss the general principle and then apply it to the production of color by thin films. Let two stones be dropped simultaneously a little distance apart in still water. There will be produced two sets of circular waves in the water with crests and troughs following each other. If we fix our

attention on a point, A, some distance ahead of the stones and half-way between them, we shall find that when the

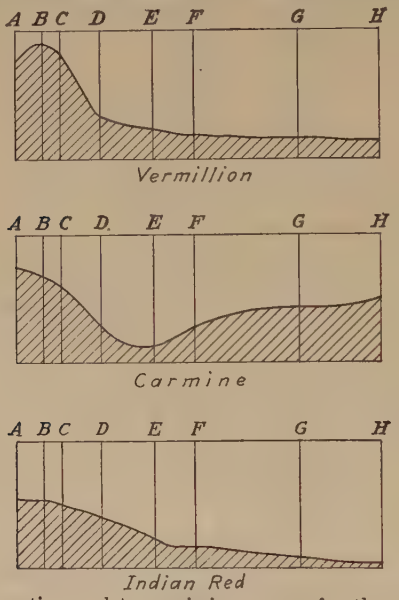


FIG. 160.—Absorption and transmission curves for three different reds.

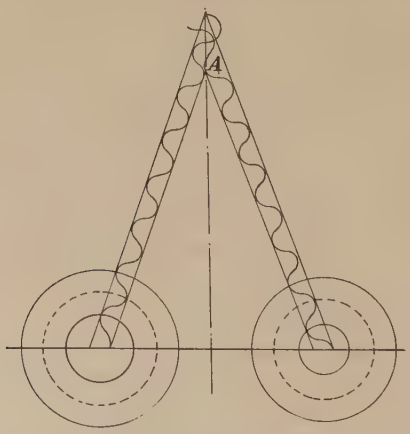


FIG. 16

two waves reach A, having traveled equal distances, either the troughs from the two waves unite to form a deeper trough or the

crests unite to form a higher crest. This higher crest or deeper trough is the result of *helpful interference* between the two waves. The figure below shows helpful interference at points a, c, and e.

Returning to our illustration of the stones, let us move the point A so that the distance from the left-hand stone to A is greater than is the distance of the right-hand stone to A by just the distance between a crest and a trough or one-half a wave-length. The two waves will arrive at A, one as a crest and one as a trough, and as their effects are added as before the result will be smooth water at A, *destructive interference.* Points b and d in the second figure represent the destructive interference between the two waves at those positions. Two light waves starting alike may in a similar way interfere helpfully or destructively. In the first case producing more intense light and in the second case, darkness.

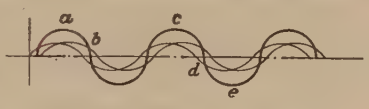


FIG. 162.—Wave interference

267. Interference Colors. Colors of Thin Films.—Everyone recalls the brilliant colors in the soap bubble and the colors of the oil film on the pavements. These colors result from a transparent film between two media.

Let us consider a thin film of glass or of oil surrounded on its upper and lower surfaces by air. R represents a ray of yellow light striking the film at its upper surface. A part of the light will be reflected in the direction A from the top of the film surface and a part will go into the film. At C, a part will again be reflected backwards and leave the film in the direction B. Now it is evident that the B part of the origina light when it reaches the top of the film from C has traveled over a path $2t$ longer than the A part and if in traversing this greater distance it has fallen behind an odd or an even number of half wave lengths it will be in condition to interfere with A. But before we can state whether this interference will be helpful, producing a bright beam, or will be destructive, producing darkness, another fact must be taken into account.

The A part of R was reflected in air against a denser medium and the B part was reflected in a denser medium against a less

denser. Both experiment and theory show that the A part is affected as if it had lost a half wave length. Now assume $2t$ to be equal to one wave length, then B and A when brought together will produce darkness since the half wave length lost by A will mean that a crest and a trough will meet. On the other hand, if $2t$ equals an odd number of half wave lengths, then there will be brightness due to A and B for there will be a meeting of two crests or two troughs.

If white light with its many wave lengths is incident on a film of varying thickness, there will be at any given point helpful interference for certain wave lengths and destructive interference for other wave lengths with the result that the white light at this point having been deprived of some of its wave lengths, will appear colored. This accounts for the colors seen in the soap bubble and the oil film. The color of mother of pearl, of some shells, of some antique glass, and of Venetian glass is due to this kind of interference.

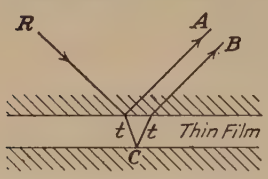


FIG. 163.—Interference by thin films.

268. Diffraction Colors.—In **Art. 190** it was stated that light proceeds in straight lines. It is necessary to modify that statement for certain conditions, as when light passes through a *very small opening*, comes up to a *sharp edge*, or to a very *small obstacle* such as a hair or a fiber. Experiment shows that it bends as it passes through the opening or comes up to the obstacle.

If on a piece of glass a large number of fine parallel lines are scratched and this plate is held before the eye to which light is coming from a slit, we shall see a bright image of the slit and on each side of it bright spectra. These spectra are produced by the bending or diffraction of the light as it passes through the transparent openings on the glass, and by interference which cuts out at any given point in the spectra all the wave-lengths except one. Figure 164 is a sketch of a simple diffraction grating using only two slits. It represents an instantaneous view of a section perpendicular to the two slits. Spherical waves from a source S are represented by

heavy and dotted lines. The heavy lines may be considered as the crests and the dotted lines as the troughs of the waves, the two being, therefore, one-half a wave apart.

When the wave front reaches the grating, it is stopped except at the two slits S_1 and S_2. From these slits two systems of spherical waves spread out to the right and interference takes place between them. When two crests or two troughs from these systems come together, the interference results in a larger disturbance in the medium, a higher crest, and a deeper

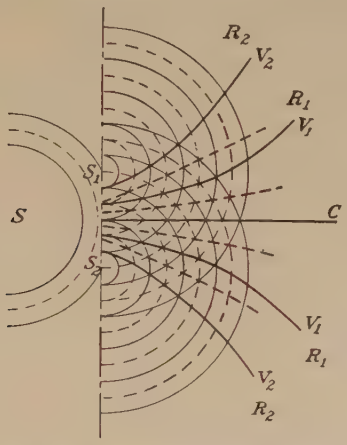


FIG. 164.—Simple diffraction grating.

trough. If a crest and a trough interfere, the result is a smaller disturbance. The heavy, full lines represent the interference resulting in greater intensity of motion, while the heavy, dotted lines indicate the interference which results in less intensity of motion. If these waves fall on a screen there will be light on the screen wherever the heavy, full lines terminate and darkness wherever the heavy, dotted lines end.

Let us assume that the original source S has been sending out violet light only and we now substitute a red source. A similar sketch would represent the result, but as the red wave lengths are longer than the violet ones, the heavy, full lines will not intersect the screen at V_1 and V_2, but at distances from C greater than V_1 and V_2. Allowing white light with all the

visible rays present to come from S, there will result on the screen a complete spectrum between R_1 and V_1 and R_2 and V_2 on each side of the white spot at C.

If a fire opal with its beautiful play of color is examined under a microscope, it is found to be covered with a multitude of small cracks or checks, so that, in an irregular way, it resembles the fine scratches on the glass with the transparent spaces replaced by reflecting surfaces. The explanation of the colors of the opal is found in the diffraction and interference which takes place.

The metallic hues in the plumage of the peacock and of the humming bird and in the wings and bodies of certain beetles, are all examples of color produced by diffraction.

Some Suggested Laboratory Exercises

1. Study of differences between colored fabrics, papers and glasses, of nearly the same hue and of widely different hues. The tint photometer.
2. Study of the colors produced by dyes. Gelatine films of the separate components.
3. Study of color produced by combining dyes. First by an analysis of the light transmitted by each and by the combined dyes. Second, by the dyeing of a fabric.

REVIEW SUMMARY

Color may refer to the sensation, to the cause of the sensation, or to pigments or paints.

Hue is the term used to denote the cause of the sensation. The same sensation may be produced by different combinations of hues.

Four general ways of producing color from sunlight; dispersion, diffraction, interference, reflection, and absorption.

A prism disperses the elements of white light into the seven prismatic colors, V I B G Y O R. The wave lengths range from about 0.00035 to 0.0007 mm.

Sunlight is complex, composed of an infinite number of light waves of different frequencies or wave lengths.

A white light can be made by mixing red, green, and blue lights.

The colors of the spectrum cannot be broken up into other colors. Each is an element.

The color of a colored transparent body is due to the mixture of the colors which it transmits.

The color of a colored opaque body is due to the mixture of the colors which it reflects.

At present there is no satisfactory way to describe a color.

One way to describe a color is to name its hue, its purity or chroma, and its brightness or luminosity.

Hue is determined by the dominant wave length in the color.

Purity or chroma is determined by stating the percentage of white light that must be added to the spectrum hue to match the sample.

Brightness or luminosity is determined by giving the percentage of light reflected; white having 100 per cent reflected and black 0 per cent.

Tones refer to those differences we notice in the same hue. If white be added to a given hue a tint results, while adding black gives a shade.

Interference results from adding two or more light waves. The result may be darkness or greater intensity of the light.

In thin films, interference destroys some of the waves in white light and the resulting color, or colors, is due to the waves remaining.

Diffraction is the bending of light waves which have passed through a narrow opening or around a small obstacle. Waves of different lengths bend different amounts. Interference then results and produces colors as in thin films.

CHAPTER XXV

PRIMARY COLORS

269. The Additive Primary Colors.—Although Newton named seven colors in the spectrum of white light, it is not necessary to have more than two or three spectrum colors to produce a white light.

Combining the following colored lights we obtain a white light which the eye cannot distinguish from noonday sunlight.

Blue + yellow
Purple + green
Blue + green + red

Any hue can be produced by the addition in proper proportion of blue, green, and red lights. Moreover, none of these hues can be produced by the addition of any other monochromatic lights. Hence, the two statements above give the reasons for calling the red, green, and blue monochromatic colored lights, the *additive primary colors* (see Fig. 165 facing p. 302).

We may express these facts by color equations:

$\frac{1}{3}\,R$ light + $\frac{1}{3}\,G$ light + $\frac{1}{3}\,B$ light = white light.
or $xR + yG + zB$ = any light hue,

where x, y, and z represent the amounts of each used in the addition.

Again,

$B + R = P$ and $R + G + B = W$. Hence $P + G = W$ and $P = W - G$.

$G + B = BG$ and $R + G + B = W$. Hence $BG + R = W$ and $BG = W - R$.

$G + R = Y$ and $R + G + B = W$. Hence $Y + B = W$ and $Y = W - B$.

Fig. 165.—Colors by addition.

Fig. 167 —An actual example of color production by subtraction.

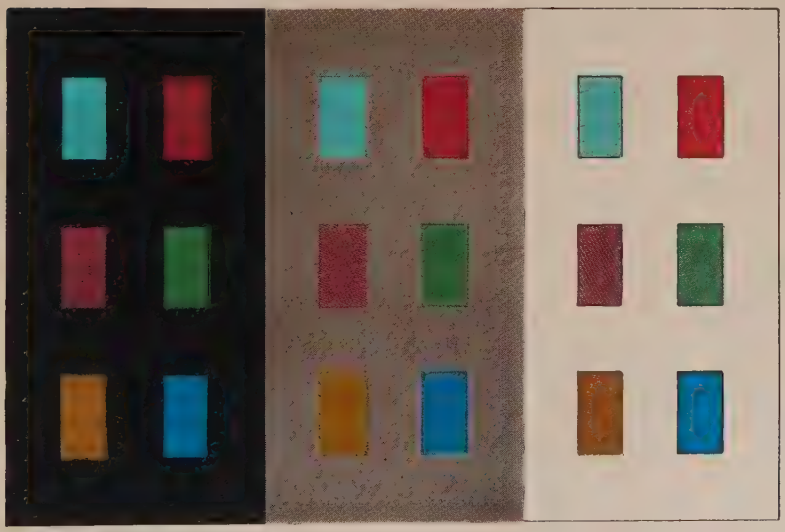


Fig. 174.—Contrast of hue.

Fig. 175.—Contrast of hues.

While we may produce any *hue* by the addition of the primaries, it does not follow that *any color* may be *matched* this way, as this would involve all the possible variations in chroma and luminosity.

Red, green, and blue or purple are frequently called the "plus hues" since, as the equations above show, to produce white light the three are added. While to produce the other three hues, white light must lose one of its elements. Hence these hues are called "minus hues."

270. Complementary Colors.—Mention has already been made of the fact that by the addition of two colored lights, white light can be produced. For light of any color a com-

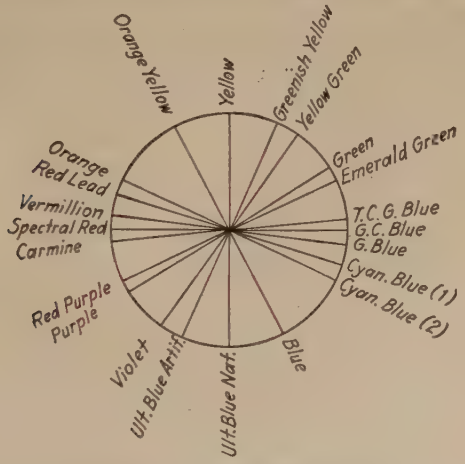


FIG. 166.—Complementary colors.

plementary color may be found, which when added to the first in the proper intensity, will produce the sensation of white. The table gives some complimentary combinations:

Red, wave length	λ 656 μμ	and bluish-green	λ 492 μμ
Orange-red, wave length	λ 608 μμ	and blue-green	λ 490 μμ
Yellow, wave length	λ 585 μμ	and blue	λ 485 μμ
Yellow-green, wave length	λ 574 μμ	and ultramarine	λ 482 μμ
Greenish-yellow, wave length	λ 564 μμ	and violet	λ 433 μμ

Complementary colors are important from an artistic point of view since they offer the greatest possible con-

trast to each other. For example, red figures on a green background.

The table above shows that each separate color does not produce an independent sensation, otherwise the different pairs of colors would not produce the one sensation of white. The effect of superimposing two different light waves on the retina is to give a single sensation. If two different sound waves reach the ear simultaneously the ear can ordinarily detect the presence of each separate note. The ear is a fairly good analyzer, whereas the eye is not.

The chromatic circle given here is one proposed by Hatt in his book, "The Colorist." The colors opposite each other are complementary.

271. Experimental Color Mixing.—The study of the colors resulting from the adding of colored *lights* cannot ordinarily be undertaken by the student because of the lack of the special apparatus. Nevertheless by the use of rotating discs, which may be colored with pigments, a very good approximation may be obtained. Vermilion, emerald-green and ultramarine blue may be used to color the discs, or more brilliant colors may be obtained from the Eastman Kodak Co's. water-color dyes sold in a "book" form. The student needs to keep in mind that the colors used are not pure colors of a small range of wave lengths and that the pigments reflect white light also.

272. The Subtractive Primary Colors.—The user of color does not as a rule produce the many beautiful color effects by adding colored lights. He adds or mixes pigments. We find at once an entirely different result. Red light and green light produce a yellow, while a red and green pigment produces a dirty brown or gray. A yellow and a blue light mixed produce a bluish white or yellowish white. A yellow pigment mixed with a blue pigment makes a good green.

So the artist and industrial color worker finds that he needs different primary colors to produce his results. These *pigmental* or *subtractive* primaries are red, yellow, and blue.

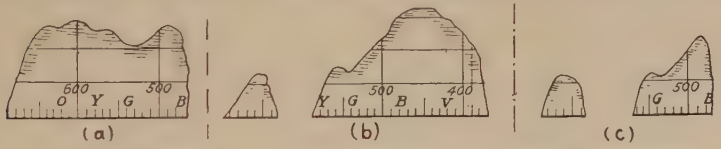
A red *pigment* + a yellow *pigment* produces an orange.
A red *pigment* + a blue *pigment* produces a violet.
A blue *pigment* + a yellow *pigment* produces a green.

The orange, violet, and green so produced are called "binary" or "secondary" colors.

If the three pigmental primaries are mixed they do not *produce a white*, but they always tend to *produce black* (see Fig. 167 facing p. 302).

We can study the differences resulting from the mixing of colored light and the mixing of pigments by using rotating discs. Paint the center of the disc with a mixture of two pigments and on the outer area paint each pigment separately, the area of each being proportional to the amount of the pigment in the mixture. On rotating the disc we get from the outer area the color resulting from the additive combination and from the center the subtractive color.

273. Explanation of Subtractive Mixture.—We have already seen the colors produced by the transmission and the reflection by colored bodies of a *part* of the white light thrown on them.



Picric acid. Indigo. Mixture of *a* and *b*.

FIG. 168.

The red glass did not transmit simply the red of the spectrum but transmitted some of the other elements in the white light, usually in lessened intensity.

The green cloth did not reflect green light alone, but reflected some of the other elements of the white light, the decrease in their intensity or the complete absence of one or more elements being due to absorption. Dyers use picric acid, a yellow dye and indigo, a blue dye, to produce a green. The three spectrographs (*a*) the yellow dye, (*b*) the blue dye, (*c*) the mixture of the two, enables one to see why a green is produced. Certain elements of white light have been absorbed, and those remaining gave a green—not a pure green as the spectrum green, but a green with other colors mixed in it.

The color resulting from the mixing of pigments is *that due to the subtraction or absorption of some of the elements in white light and to the varying intensities of those elements which are left.*

274. Complementary Pigmental Colors.—Each of the binary or secondary colors, orange, green, violet, is complementary to the pigmental primary not used in producing it. The pigmental complementaries when mixed produce a gray.

Orange = $R + Y$ is the complementary of blue.
Green = $Y + B$ is the complementary of red.
Violet = $B + R$ is the complementary of yellow.

275. Tertiary Colors.—By a combination of the secondary colors together in pairs or with a pigmental primary, we obtain the colors called tertiary colors.

Orange + Green = citrine or olive.
Green + Violet = slate.
Violet + Orange = russet.
2 Yellow + Violet = citrine or olive.
Yellow + Blue + Gray = $2Y + B + V$ = sage.
Yellow + Red + Gray = $Y + O + V$ = terra cotta.
Red + Blue + Gray = $Y + 2V$ = plum.

276. Color Mixture by Juxtaposition.—A surface covered by small dots of pigments of different colors when viewed at some distance, will appear of a uniform color. Consider a surface with small dots of yellow and blue pigments. The color of the surface will be due to the light reflected from it and we may assume the following reflections, the relative amounts being suggested by the size of the letters:

$$(B + g) + (Y + g) = 2g + (B + Y).$$

But $(B + Y)$ lights = W light. Hence the surface will be a green diluted with white. The color produced is due to addition and will have more chroma than the green produced by the mixture of the two pigments. Any pigment hue can be matched by dots of pigments of the additive primaries.

277. Colored Objects under Colored Lights.—We have seen that a colored object owes its color to selective absorption. The white light falling on the object has some of its hues absorbed and the mixture of those reflected determines the colored appearance of the object.

Consider the dyed wool discussed in **Art. 258.** It was a green with a little red in it. The other hues of the white

light falling on it were absorbed. If, now, this piece of wool is illuminated with a blue light, which the wool absorbs, it is easy to see that it will look black. Again, refer to Fig. 154 in **Art. 258,** and assume that the ultramarine blue fabric is illuminated by a light which has no blue in it but has green and yellow elements with the green element much the stronger. It is not difficult to see that the color of the fabric would be greenish with some yellow in the green.

Pigments of the same hue may reflect different elements of the white light and different relative amounts of the same elements. The ordinary artificial light sources differ in their chromatic composition in the same way. These variables make it difficult to predict what changes in hue will be produced when a colored object is viewed under an artificial light. However, it is easy to see that there will be a change in the appearance of the object.

The table below gives some color changes produced under a given set of conditions:

Object	Appearance under:			
	Red	Yellow	Green	Blue lights
Red	Red	Orange	Brown	Violet
Yellow	Orange	Yellow	Yellowish-green	Green
Deep green	Reddish black	Yellowish-green	Intense green	Greenish blue
Light blue	Violet	Yellowish-green	Greenish blue	Vivid blue

As we shall see later, the color characteristics of all artificial illuminants differ from that of sunlight. Therefore, we never see any colored object under artificial light in its true color.

When colored samples of cloth, ribbon, or yarn are to be matched, sunlight or an artificial light which has been made to match sunlight, should be used.

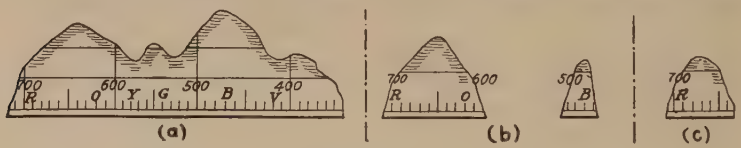
In our homes, the increasing use of the indirect or semi-indirect luminaire which throws a greater part of the light to the ceiling, makes the ceiling color important. A light-green

ceiling, for example, will reflect to all colored objects in the room greenish light and this may produce undesirable color changes.

Everyone has noticed the decidedly unpleasant color change produced on the face of women carrying a green or blue umbrella.

In some of our theatres the entire stage setting is changed by simply throwing a certain colored light on it. A winter scene may be changed into one of spring.

277. Dichroism.—If a beam of white light be passed through a strip of yellow gelatine, the transmitted light is yellow; if several colored strips are used, the transmitted light changes from a yellow to an orange; and if the strips are transparent enough, they may be increased until the color transmitted is red. This property of nearly all dye stuffs, of changing hue



(*a*) Dilute. (*b*) Strong. (*c*) Concentrated.

FIG. 169.—Examples of dichroism in dyes.

with increase of the amount of the coloring matter, is called "dichroism." Different dyes show this property in different degrees and those that are strongly dichroic make poor dye material, because plain surface and velvet fabrics dyed with the same coloring matter will have different hues. A study of the absorption of a solution of naphthol yellow and methyl violet of different thicknesses will make clear the reason for the change.

In the table a few examples of dichroism are given:

Dye	Color in:	
	Thin layer	Thick layer
Magenta	Bluish pink	Scarlet
Gamboge	Yellow	Orange
Quinoline blue	Clear blue	Fine red
Malachite green	Blue green	Reddish purple
Methyl violet plus acid	Violet blue	Claret red

278. Optical Properties of Fabrics and Weaves.—The two optical properties of a fiber are luster (surface reflection) and transparency. Silk is known to be a lustrous fabric, while wool and cotton are less so. The microscope reveals the difference in structure which at once accounts for the different reflecting properties of these fibers. The silk fiber is seen to consist of nearly cylindrical rods which are smooth and shining like the surface of a glass rod. Moreover, the silk fibers form threads nearly parallel to each other, thus giving a surface of high reflecting power. Because of the parallelism, the light is largely reflected in one plane. It may be said that the fibers of China grass or Ramie are very similar in structure to those of silk and so have similar properties.

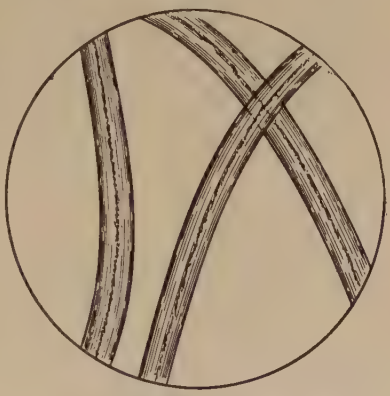


FIG. 170.—Silk fiber as seen under the microscope.

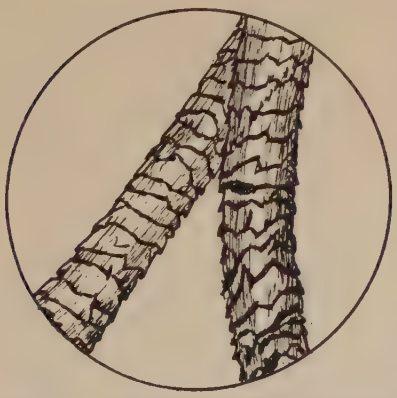


FIG. 171.—Wool fiber as seen under the microscope.

The wool fiber, with its serrated edges and scales, does not offer such a continuous surface to the light and the reflected light is less, as well as being more diffused. The difference between the merino and mohair fibers accounts for the former being a non-lustered wool while the latter is a luster wool. The scales of the mohair fiber lie closer and firmer to the stem, approximating a smooth surface.

The cotton fiber is a flattened and twisted tube-like fiber which scatters or diffuses the light to a greater degree than the wool fiber. The change produced by mercerizing the fiber is due to the action of the alkali in causing the fiber to shrink and to assume a more nearly cylindrical shape. Jute and linen are better than cotton in their luster and the fiber is found to be smoother and more equal in formation.

An increase in the luster or reflecting power and the transparency of the dyed fiber increases the difficulty of matching colors. The spectral character of the dye has a better chance to alter the appearance of the colored fiber. Dyed cotton is easier to match than wool, and wool, again, is easier to match than silk. The same factors make the effect of different illuminants greater on the dyed silk than on the dyed cotton.

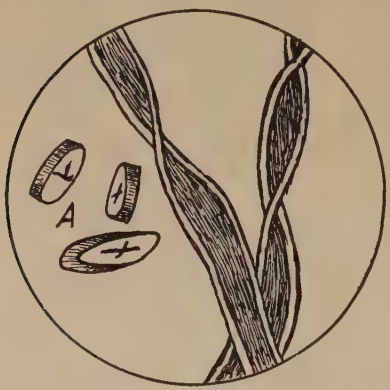


FIG. 172.—Cotton fiber as seen under the microscope. *A*, mercerized fiber.

279. Surface Reflection. Note the dark-blue color of a copper sulphate crystal. Now crush the crystal until it is in a finely powdered state. We see its color is a very faint blue. If we add to the powder a little water the darker blue color is nearly restored.

The explanation of these facts is simple. The light which was incident on the copper-sulphate crystal was partly reflected from the surface, which was polished, mirror like, as *white* light. It had not gone into the crystal and so no absorption of any of its elements had taken place. Also, the surface being mirror-like had reflected this light very largely in one direction. The part of the incident light that came to the eye after the crystal had absorbed some of its elements was a *dark blue* due to this absorption and also to the fact that it was not viewed through a veil of diffused white light.

When the crystal was powdered, having many very small reflecting surfaces lying in different planes, the white surface-reflected light was diffusely reflected and the blue light came to the eye mixed with this white light. The blue color was diluted. When the powder was covered with a thin film of water, this in a measure restored the mirror-like surface and this, as in the case of the crystal, sent the white surface reflected light in one direction. Looking at the powder now, the blue light is received from the crystals without the veil of diffused white light.

The light that is reflected from the surface of fabrics is partly white and partly colored. From the *superficial* surface it is white light and from the thin surface layers it is faintly colored. If a given fiber and its dyestuff are transparent, then more of the light reflected from the fabric is the light that has penetrated into the fiber, had some of its colored constituents absorbed by the dye, and so comes to the eye as highly colored light. This colored light will be mixed to a greater or less degree with the white light from the surface reflection.

The fact that silk viewed from one position shows a rich saturated color, with little white light, and from a different position appears a pale color, but always having a sparkling play of color, can now be easily explained. The silk fibers take the dye through and through, and, being fairly transparent, permit the light to come to the eye deeply colored when, because of the nearly parallel compact bundle of fibers, the white surface light is reflected in some direction away from the eye. But the color is much diluted when the position of the eye is such as to receive both the deeply colored light and the white reflected light.

Woolen fabrics in comparison with silk appear dull and tame and with a diluted color. The dilution of the color is due, not so much to the lessened transparency of the wool fiber as to the scattering of the surface-reflected light in all directions so that the colored light is lessened in intensity. The wool fabric compared with the cotton has a much richer appearance and the color is more saturated. The cotton fiber

does not take the dye so completely, is not so transparent, and its surface reflection is widely scattered. These facts account for its lack of luster and a dullness and sameness in its appearance as compared with wool.

In velvets, an attempt is made to prevent surface reflection by presenting the cut-off ends of the fibers, which are poor reflectors, to the light. The rays then penetrate between the fibers which are set on end, and after repeated reflections within the pile, the rays finally come from the fabric as richly colored light with little or no white surface light. In the case of silk velvet, these conditions are realized. With cotton velvet, especially when a little worn, the surface reflection is much greater and the cotton velvet has a dull, washed-out appearance.

In this connection, attention may be called to the fact that some, at least, of the aniline dyes, furnish to fabrics a colored light so rich and pure as to be undesirable. This is especially true when rather large areas are seen as in dresses, rugs, etc. The vegetable and animal dyes with which old oriental rugs are colored produce a more subdued and, in general, more pleasing appearance than do the modern dyes with which the rugs are colored.

Dichroism must evidently play a part in the color effect of velvets and silks and to a much less degree in wool and cotton fabrics. Some flat olives and moss greens can be produced by naphthol-yellow and methyl-violet 3B, and on plain surface materials the resulting color is a sage green, but on velvet their dichroic property produces a reddish-bronze appearance.

Certain dyes, used largely in silk coloring, are fluorescent. On looking down on them the color is different from that coming by transmission through the fiber on looking across the fabric. Fluorescence is that property of certain dye materials whereby they show one color by reflected light and a different color by transmitted light. If the dye, *rhodamine*, is combined with wool green, a tone of violet or heliotrope may be produced. But by reflected light, the color is a peculiar reddish hue.

280. Surface Reflection in Painting.—We have just pointed out the part played by surface reflection in the color appear-

ance of fabrics. Artists know that the appearance of a pigment is greatly influenced by the medium which is used with it. Drawings in crayons, water colors and oil, all using the same pigment, do not look alike. Crayons, and water colors to a somewhat less degree, reflect not only the colored light but also the white surface light. By the use of oil or varnish with the pigment, the white surface reflection is greatly reduced. The fresco artist and his humbler brother, the wall decorator, both work with their color medium in a wet condition, which increases the intensity of the color owing to the cutting down of the surface reflection. But when the fresco painting is dry, the colors are all diluted, and harmonious coloring and uniformity of hue are, therefore, more difficult to attain.

Some Suggested Laboratory Exercises

1. Study of dichroism. Liquids and fabrics.

REVIEW SUMMARY

Additive primary colors, red, green, blue.

Any hue can be produced by adding different amounts of the three primaries.

Complementary colors, two colored lights which when mixed, produce a white light.

Subtractive primary colors, or pigmental primaries, red, yellow, blue.

Complementary pigmental colors, two colors which when mixed produce a gray.

Tertiary colors result from mixing of one or two pigmental primaries with a gray.

Colors by juxtaposition, color due to the mixture of the colored lights coming from a surface covered with small colored dots.

Colored light affects the color of all colored objects.

All artificial lights are different in composition from sunlight, hence they change the appearance of colored objects.

Dichroism, a property of dyes of changing hue when the amount of dye is increased.

Optical properties of textile fibers.

Surface reflection, a factor in reducing the chroma of colored objects.

Some Reference Books on Color

Snow and Froehlick, "Theory and Practice of Color."
Luckiesh, "Color and Its Applications."
Hurst, "Color."
Paterson, "Textile Color Mixing."
Paterson, "Color Matching on Textiles."

CHAPTER XXVI

CONTRAST AND HARMONY

281. Subjective Colors.—The color of substances so far studied has been due to the nature of the substances or their surfaces, or to the character of the light by which they were illuminated. The color phenomena to be studied now are color effects which are produced, or influenced, by other sensations of color, occurring either before the former in time or appearing simultaneously. Colors produced in this way are called subjective colors and are due to contrast. There are two kinds of contrasts, simultaneous and successive.

282. Simultaneous Contrast.—Simultaneous contrast results from seeing two or more hues at the same time and is considered in two forms: contrast of tone and contrast of hue.

(*a*) *Contrast of Tone.*—Contrast of tone results when we look at different tones of the same hue.

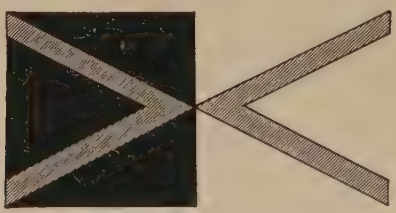


Fig. 173.—Contrast of tone.

The illustration shows two *V* figures made from the same gray, one placed on a white background and one on a black background. The one on the white ground appears darker by several shades.

Luckiesh describes a striking demonstration of tone contrast. Look at a gray paper through a hole in a white unilluminated screen. It will appear very bright in contrast to its dark

surroundings. By illuminating the white surroundings, the bright gray will appear dark by contrast.

(*b*) *Contrast of Hues.*—The simplest case of simultaneous contrast of hue is the use of a simple color with white, gray, or black backgrounds. See Fig. 174 facing p. 302.

All hues look brighter on the black and darker on the white. The effect on the gray is influenced by its tone and that of the hues.

Rood[1] shows the change produced in adjacent hues by simultaneous contrast.

Color Pairs	Change Due to Contrast
Red	Inclines to violet
Orange	Inclines to yellow
Red	Inclines to violet
Yellow	Inclines to greenish yellow
Red	Becomes more brilliant
Green	Becomes more brilliant
Red	Inclines to orange
Blue	Inclines to green
Red	Inclines to orange
Violet	Inclines to blue
Orange	Inclines to red orange
Yellow	Inclines to greenish yellow
Orange	Inclines to red orange
Green	Inclines to bluish green
Orange	Becomes more brilliant
Blue, cyan	Becomes more brilliant
Yellow	Inclines to bright orange
Green	Inclines to blue
Yellow	Inclines to orange yellow
Cyan blue	Inclines to bright blue
Green	Inclines to yellow
Blue	Inclines to violet
Green	Inclines to yellowish green
Violet	Inclines to reddish
Blue	Inclines to greenish
Violet	Inclines to reddish

In general, the effect of simultaneous contrast is to throw farther apart the members of the pair. In the pairs which are complementary, and so already as far apart as possible, the effect is to make each more brilliant and distinct.

[1] From "Colour" by George H. Hurst Scott-Green Wood & Son.

Place a gray figure on a green background. The gray will take on a pinkish hue and the hue will be strengthened if a sheet of white tissue paper is placed over the two. The contrast hue induced in this manner is generally an approximation of the color complementary to the exciting color. Chevreul relates the following incident which illustrates how simultaneous contrast may play a very important part in color combination. Plain red, violet blue, and blue fabrics were given to certain manufacturers to ornament with black patterns. When the goods were finished it was claimed that the patterns were not black, that those on the red fabric had a greenish cast, those on the violet blue a greenish yellow, and those on the blue a copper color. Chevreul, to whom the dispute was referred, covered the colored fabrics with white paper, exposing the patterns only; the result showed that all the patterns were black, the color observed being due to contrast. The remedy was found to be to dye the patterns not a pure black but to give them a slight tint similar to the background.

Experiment shows that those colors which are tints and broken colors and those which are shades, exhibit the phenomena of contrast more than the full colors. The latter seem to impress their hues upon us so strongly that there is little room for the false judgment which is the cause of the effects of simultaneous contrast. The admixture of white light always increases the effect. If black letters are printed on a colored background, one may notice a touch of contrasting color on the black, but if both are covered with white tissue paper and then observed, the contrast color is much more evident. (See Fig. 176 facing p. 316.)

The effects of simultaneous contrast may be summarized as follows: *Colors can be produced where none exist, as on a gray surface; colors can be changed in hue and their brightness can be increased or decreased; and if two colors are put in juxtaposition, each color will be changed as if some of the complementary colors of the other color had been mixed with it.*

283. Successive Contrast.—If on a large piece of gray paper a small red square is placed and closely looked at for some seconds, we find on suddenly removing the red strip, that a

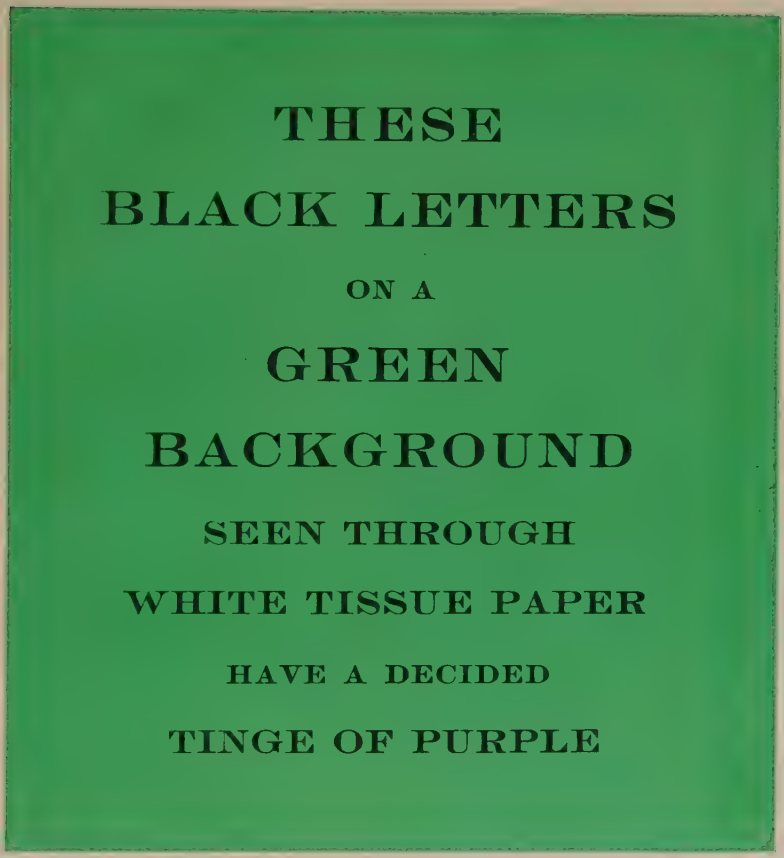


Fig. 176.—Contrast of colors.

faint green image takes its place. If other colors replace the red, we find that the color of the after image is always the complementary. These color changes are entirely subjective and find their explanation in the fatigue of special sets of color nerves. If the green nerves had been fatigued, then when the eye received light from the gray patch, which we may assume to be composed of red, green, and blue rays, the red and blue nerves, not being fatigued, respond strongly to the gray light, while the green nerves, being tired, respond more feebly. The result is apparently to give to the spot a reddish hue.

This fatigue of one set of nerves and a consequent lessening of the sensation is often experienced, though usually unconsciously, when a person spends considerable time in examining different kinds of one-hued fabrics. If several red fabrics are successively examined, then still other red fabrics, these latter will appear dull and unsatisfactory, but if the eye is rested for red by looking at green fabrics for a short time and then returns to the reds, they are found to have taken on entirely different tones. Successive contrast plays a considerable part in the effect which colors produce. The red-tired eye, in turning to blue colors, sees them with a greenish tinge and even the whites take on a green tone. The following table from[1] Hurst gives an idea of the changes in color produced by successive contrast:

If the Eye Has First Seen	then Looks at	the Latter Will Appear
Red	Orange	Yellow
Red	Yellow	Greenish yellow
Red	Green	Bluish green
Red	Blue	Greenish blue
Red	Violet	Bluish green
Orange	Red	Reddish violet
Orange	Yellow	Greenish yellow
Orange	Green	Bluish green
Orange	Blue	Tinted with violet
Orange	Violet	Bluish violet
Yellow	Red	Reddish violet
Yellow	Orange	Reddish orange
Yellow	Green	Bluish green
Yellow	Blue	Violet-blue

[1] From "Colour" by George H. Hurst. Scott, Green Wood & Son.

If the Eye Has First Seen	then Look at	the Latter Will Appear
Yellow	Violet	Bluish violet
Green	Red	Tinged with violet
Green	Orange	Reddish orange
Green	Yellow	Orange-yellow
Green	Blue	Violet-blue
Green	Violet	Reddish violet
Blue	Red	Orange-red
Blue	Orange	Yellower
Blue	Yellow	Orange-yellow
Blue	Violet	Yellowish green
Blue	Green	Reddish violet
Violet	Red	Orange-red
Violet	Yellow	Slightly yellowish
Violet	Orange	Yellowish orange
Violet	Green	Yellowish green
Violet	Blue	Greenish blue

An inspection of the table shows that the color change brought about by successive contrast is such as would result from mixing the complementary color of the surface first looked at with the color of the second surface. If a green surface is first looked at and then a blue one, the color of the blue surface will appear a violet, the complementary red plus the blue, giving violet.

284. Harmony.—In what we have studied so far under the topic of color, we have had facts which are capable of demonstration in a more or less definite way. But the problems of harmony of color combinations are outside laboratory methods. Rood says:

> Why a certain combination of colors pleases us or why we are left cold or even somewhat shocked by another arrangement are questions for which we cannot always frame answers that are satisfactory even to ourselves. There is no doubt that helpful and harmful contrast has a very great influence on our decision, but besides this, we are sometimes influenced by obscure and even unknown considerations. Among these may perhaps be found inherited tendencies to like or dislike certain combinations or even colors; influence of the general color atmosphere by which we are surrounded; training; and also a more or less delicate nervous susceptibility.

The experience of color-educated persons must be taken as the basis of judgment of harmony and the table below attempts

to express concretely such judgments. It may be noted that both the *tone* and *brilliancy* of the colors affect the result and may change a combination from good to bad or the reverse. The table is due primarily to work of Brucke and Rood:

HARMONY OF TWO COLORS

Crimson and orange	Bad
Crimson and yellow	Inferior
Crimson and green	Strong but harsh
Crimson and blue	Good
Crimson and violet	Bad
Crimson and gold-yellow	Good
Scarlet and yellow	Bad
Scarlet and green	Inferior
Scarlet and greenish-blue	Good
Scarlet and blue	Good
Scarlet and violet	Bad
Orange and yellow	Poor
Orange and yellow-green	Fair
Orange and green	Strong—poor
Orange and green-blue	Fair
Orange and blue	Good
Orange and violet	Strong—good
Orange-yellow and crimson	Poor
Orange-yellow and scarlet	Poor
Orange-yellow and green	Bad
Orange-yellow and blue-green	Bad
Orange-yellow and green-blue	Fairly good
Orange-yellow and blue	Excellent
Orange-yellow and violet	Good
Yellow and crimson	Poor
Yellow and green	Bad
Yellow and blue-green	Very bad
Yellow and blue	Only fair
Yellow and violet	Very good
Green and blue	Very poor
Green and violet	Moderate
Green and red	Good

285. Combinations of Three Colors, a Color Triad.—The combination of three colors offers still greater difficulties. When the range of colors are spaced equally on a circle, we find the three colors which are 120 deg. apart form good combinations. If an equilateral triangle is placed at the center of the circle and rotated, the points of the triangle will

show the three colors that may be combined to produce a good color combination.

286. Generalizations on Harmony.—We can generalize some of the results in the tables by using the chromatic circle above. If the different hues which are less than about 80 deg. apart are considered, it will be found they make poor combinations because of harmful contrast. When hues are more than 90 deg. apart the contrast is helpful to the combination. It does not follow, however, that the hues which are farthest apart, that is, the complementary hues, always make the best combinations. The contrast being a maximum may result in a harsh combination.

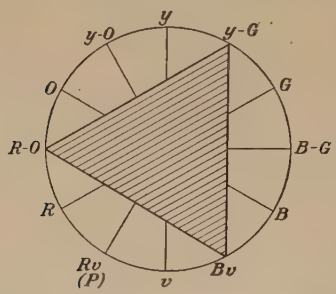


FIG. 177.—Harmonious color triads.

If the chromatic circle above is divided into halves along the yellow-violet line, the left half contains the warm hues, beginning with yellow and decreasing in warmth to the violet. The right half contains the cold hues, increasing in coldness from the top to the bottom of the circle.

In the triad combinations the better combinations are those which contain two warm hues and one of the cold hues.

REVIEW SUMMARY

Subjective colors are those produced or influenced by other sensations of color.

Simultaneous contrast results when two or more colors are seen at the same time.

Contrast of tone when we look at two tones of the same hue.

Contrast of hue when we look at two hues.

Effect of simultaneous contrast is to throw farther apart the members of the pair, to produce color where none existed and to give the appearance to a color of greater or less brightness.

Successive contrast, the change produced in the second color of a pair when one looks at the first color then at the second.

Effect of successive contrast, that the color change is such as would result from mixing the complementary of the color first looked at with the color of the second.

Harmony of colors, no fixed standard.

ELECTRICITY

CHAPTER XXVII

ELECTRICITY AND ELECTRICAL UNITS

287. What is Electricity?—It is always a surprise to the layman and the student beginning the study of electricity when they find that this question is more or less unanswered even today. So many facts about electricity are known and its applications serve so many of our present-day needs that we feel that the nature of electricity should be known. But we are in the same uncertainty concerning the nature of matter. Matter and electricity have some properties in common. One common property of both is that they cannot be created or destroyed. The sum total of each remains the same. The early theories of electricity considered it to be a fluid or two fluids and as a result many of the terms used to describe the behavior of electricity are those used in the study of fluids. We speak of electricity flowing in a wire just as we say water flows in a pipe. Conductors of electricity offer a resistance to its flow and pipes offer a resistance to the flow of water.

In very recent years we have come to know more about the nature of electricity and perhaps we will not be far wrong if we say that electricity *is electrons*. Our knowledge of electrons permits us to say that all electrons have the same mass and the mass is very small even in comparison to the mass of an atom. All electrons have a negative charge and what we call an "electric current" is a stream of moving electrons. These brief statements must suffice for us.

We think of electricity as being consumed in the electric lamp or the electric toaster. But the dynamo, or the generator as it is called, in the central power station, is a device for supplying us with energy and it is the energy we pay for, not the electricity. The moving electricity possesses energy and it is this energy which furnishes our light, heat, and power. The electricity flows back along the wire to the dynamo, undimin-

ished in amount. We can get a close analogy if we imagine some form of water wheel or motor to be placed in one of our water pipes which is connected with the city pumping plant. Instead of letting the water, after it has operated the motor, go to waste, assume it returns through a pipe to the pumping station, where it is again put into circulation. The pumping plant is now the generating station for the energy used by the motor, and the city plant is not furnishing us with water but with energy carried by the moving water.

Keeping in mind our partial ignorance of the nature of electricity; that it cannot be created or destroyed; that it is used as one of the most convenient carriers of energy; and that our descriptive terms are largely taken from the old idea of its being a fluid, we may speak and think of it as if it were a kind of matter.

288. Historical Sketch.—Primitive man must have been familiar with the crackle and sparkle of his dry hair when he ran his hand through it and the attraction of his hair for the hand. The Egyptians, with their dry climate, surely observed the effect of stroking the fur of their venerated cats. But it remained for Thales, who lived in the sixth century B. C., to record the discovery of the attractive property of the rubbed substance for the rubbing substance. His discovery was made with amber. As the Greek word for it is "elektron," substances which had this property of attraction were called "electrics," and later the word "electricity" was given to the supposed fluid which produced the attracting property of these substances.

Comparatively little more was known about electricity until the eighteenth century, when Benjamin Franklin made one of the first and most important applications. As a result of his famous kite experiment and others, he announced the possibility of protecting our homes from the electricity in the clouds, the lightning, by the use of pointed rods.

Volta in 1793, by his discovery that electrical energy could be obtained by chemical means, laid the foundation for the various types of cells. The modern "dry cell," used for door-bells, is one of the types most familiar.

The electric bell grew out of the accidental discovery of Oersted, in 1819, that a wire carrying an electric current has properties similar to a magnet.

The dynamo and the motor started with the discovery of electromagnetic induction, by Faraday, in 1831, and by our own Joseph Henry. The early development of the dynamo and the motor in this country was largely due to the work of men like Brush, Edison, and Westinghouse.

Davy in 1802 produced an arc light from a battery current, and Edison, about 1880, made one of the first commercial electric incandescent lamps. The carbon lamp in various forms has been *the lamp* for home lighting, but in 1900 the tungsten lamp made its appearance and is rapidly displacing the carbon lamp because of its greater efficiency.

The telephone, which is based upon the work of Faraday in electromagnetic induction, was the invention of Alexander Graham Bell about 1876.

Electric heating and cooking, making use of the heating effect of electricity flowing in a wire, are having the beginnings of their development now.

289. Electrical Units.—Everyone in this day and age is familiar with some of the terms used in the study of electricity even if the exact meaning of the terms is unknown. *Amperes*, *volts*, *ohms*, and *kilowatts* are not strangers as mere words.

We shall get our introduction to these terms by comparing them with the more familiar terms used concerning the flow of water.

	Water	Electricity
Quantity is measured in.....	Gallons	Coulombs
Rate of flow is measured in...	Gallons per second	Amperes (Coulombs per second)
Pressure is measured in.....	Pounds per square inch	Volts
Rate of doing work is measured in.....	Horsepower	Watts
Energy used is measured in...	Horsepower-hours	Watt-hours or Kilowatt-hours

We are seldom concerned with the quantity of electricity used in any device but we do note more or less the amperes.

Our toaster takes 5 amp., a lamp 1 amp., an electric hot plate, or heater, 10 amp. or more. In thinking about the amperes in a given device we think of a *quantity*, whereas amperes indicate the rate of flow of electricity. Water flowing at the rate of so many gallons per second gives no knowledge of the *amount* of water flowing unless we specify a time of flow. Amperes give a rate only unless we specify the time the current was flowing. Of course we can compare the amount of electricity required by different devices if we assume a constant time and note the rate of flow in amperes.

To cause water to flow in a pipe or electricity in a wire, a pressure is required. The unit of electrical pressure is the *volt*. An electrical pressure of 220 volts, other conditions being constant, will cause a greater rate of flow of electricity than an electrical pressure of 110 volts, the pressure most common in our homes.

When water is flowing in a pipe or electricity in a wire, the pipe or wire offers a resistance to the flow. The unit of electrical resistance is the *ohm*.

These three units are defined more concretely as follows:

The International Ohm is the resistance offered to an unvarying electric current by a uniform column of mercury at the temperature of melting ice, 14.4521 g. in mass, and of a length of 106.300 cm.

The International Ampere is the unvarying electric current which when passed through a solution of silver nitrate in water, deposits silver at the rate of 0.001118 g. per second.

The International Volt is the e'ectrical pressure which, when steadily applied to a conductor whose resistance is one International Ohm, will produce a current of one International Ampere.

The *rate* at which energy is being furnished to a water motor is not measured by the rate at which the water is passing through, that is, gallons per second, but by the number of gallons of water used per second, multiplied by the difference in pressure between the water inlet and outlet of the motor. The rate at which electrical energy is being furnished to a lamp, a toaster, or a motor is measured by the electrical

pressure in volts multiplied by the rate of flow of the current in amperes. Volts times amperes equals the rate of furnishing electrical energy. The unit is called a *watt*. 1 volt $\times$ 1 amp. = 1 watt. A lamp taking ½ amp. on a circuit of 110 volts, is using energy at the rate of 55 watts. An electric iron rated at 550 watts requires a current flowing at the rate of 5 amp. The horsepower unit in mechanics and the watt are terms used to denote the rate of using energy or doing work and do not give any indication of the *amount* of energy used or the work done.

Nearly all the electrical appliances used in the home are rated in watts. If we desire to know *how much* electrical energy has been used in a given appliance and, therefore, to know the cost of the operation, we need another unit. This unit is the *kilowatt-hour*. The kilowatt is simply 1,000 watts, a rate, and the time selected is the hour. A kilowatt-hour is then a unit of amount of electrical energy. If a 100-watt lamp burns for 10 hours, the energy used is 1 kw.-hr. If a 550-watt electric heater is used for 5 hours, the energy used is 2.75 kw.-hr.

290. Ohm's Law.—One of the most used relations in electricity is the one expressing the relation between the current in amperes, the resistance in ohms and the electrical pressure in volts. As stated by Dr. Ohm it is:

$$\text{Current in amperes} = \frac{\text{pressure in volts}}{\text{resistance in ohms}} \text{ or } I = \frac{V}{R}.$$

Illustrative Problems

1. An electric iron is used on a 110-volt circuit and takes 4.5 amp. What is its resistance? What is the rate of using electrical energy? How much energy is used in 3 hours?

From Ohm's law:

$$4.5 = \frac{110}{R}, \text{ hence } R = 24.4 \text{ ohms.}$$

From definition of a watt:

$$4.5 \times 110 = 495 \text{ watts.}$$
$$495 \text{ watts} = 0.495 \text{ kw.}$$

From the definition of a kilowatt-hour:

$$0.495 \times 3 = 1.485 \text{ kw.-hr.}$$

2. A certain electric lamp is rated as 150 watts and is used on a circuit of 110 volts. What is the current in amperes? What is the resistance of the lamp?

$$150 \text{ watts} = IV, \text{ therefore } \frac{150}{110} = 1.36 \text{ amp.}$$

$$1.36 \text{ amp.} = \frac{110}{R}, \; R = 80.9 \text{ ohms.}$$

3. An electric doorbell requires 6 amp. to operate it and has a resistance of 0.5 ohm. What voltage batteries are required?

$$6 = \frac{V}{0.5}, \text{ hence } V = 3 \text{ volts.}$$

4. An electric oven used 1.8 kw.-hr. of electrical energy in 2 hours on a 110-volt circuit. What was the current in amp.

$$\frac{1.8}{2} = 0.900 \text{ kw.-hr. for 1 hour} = 900 \text{ watts.}$$

$$900 \text{ watts} = I \times 110, \text{ hence } I = 8.18 \text{ amp.}$$

5. A $\frac{1}{20}$-horsepower sewing machine takes 0.339 amp. when used on a 110-volt circuit. What is the rate of furnishing energy in watts? What is the cost of running it for 10 hours if electrical energy costs 8 cts. a kilowatt-hour?

$$\text{Watts} = 0.339 \times 110 = 37.29.$$

$$37.29 \text{ watts} = 0.0373 \text{ kw.}$$

$$0.0373 \times 10 = 0.373 \text{ kw.-hr.}$$

$$0.373 \times 8 = 2.98 \text{ cts.}$$

Study Exercises

1. A 32-cp. carbon lamp takes 100 watts. If the voltage at the lamp is 115 volts, what is the current? How many kilowatt-hours are used if the lamp is burned 1,000 hours? At 10 cts. a kilowatt-hour what was the cost of the light?

2. A 40-watt tungsten lamp burning 1,000 hours and giving the same amount of light as in Exercise 1, will cost how much for the electrical energy used at the same price as in Exercise 1?

3. Add to the cost in Exercise 2, the price of the lamp, 23 cts., say, what is the saving in using the tungsten lamp as compared with the carbon lamp?

4. How many hours would the tungsten lamp have to burn before the saving in the energy used would pay for the lamp?

5. An electric toaster is stamped 440 watts. On a circuit of 110 volts, what current will it take? What is its resistance? At 10 cts. per kilowatt-hour what is the cost of making six pieces of toast, the toaster being used 10 min.?

6. A sewing-machine motor took 4 amp. on a 115-volt circuit. Find the wattage, and the kilowatt-hours if the machine was run 2.5 hours, and find the cost at 10 cts. a kilowatt-hour.

7. An electric iron takes 500 watts. A gas iron consumes 19 cu. ft. of gas per hour. Compare the cost of the two for 4 hours' continuous service, electricity at 10 cts. a kilowatt-hour and gas at $1 per 1,000 cu. ft.

8. In an electric oven a 4.5-lb. rib roast of beef was cooked for 3 hours taking 250 watts. Find the cost of cooking at 10 cts. a kilowatt-hour.

9. A six-cup coffee percolator required 4 amp. on a 110-volt circuit for 10 min. to make coffee. How many kilowatt-hours were used?

10. A washing-machine motor is rated as ¼ hp. If 746 watts = 1 hp., how many kilowatt-hours were required to run the washer for 90 min.?

11. If a doorbell takes 5 amp. and has a resistance of 0.6 ohm, what voltage will be required?

12. What is the resistance of the heating coils in an oven which takes 1,800 watts, the voltage being 115?

13. Compare the current taken by a 40-watt, 100-watt, and 150-watt lamp used on the same 110-volt circuit.

Some Suggested Laboratory Exercises

1. Use of voltmeter and ammeter and the application of Ohm's law to find the resistance of electrical appliances found in the home.

2. Use of kilowatt-hour meter in connection with data obtained in Exercise 1 to work out the relations between ohms, volts, amperes, watts, kilowatt-hours, time.

REVIEW SUMMARY

Electricity cannot be created or destroyed.

Electricity is electrons, the mass of each of which is much smaller than that of the atoms. They have a negative charge and a current of electricity is a stream of moving electrons.

Using electricity simply means using the energy which it carries.

The history of electricity begins about 600 B. C. in the discovery of the attractive property of a rubbed substance. Franklin identified electricity and lightning. Volta (1793) laid the foundation for our batteries —electrical energy from chemical energy. Oersted, 1819, discovered the magnetic effect of a current.

Faraday and Henry in the discovery of electromagnetic induction made possible the dynamo, the motor, and the telephone. Davy, Edison, and others developed electric lighting.

Bell developed the telephone about 1876.

Electric heating and cooking devices are modern in their extensive use.

Electrical units: *Ampere*, rate of flow of electricity; *ohms*, the electrical resistance conductors offer to the flow; *watts*, the rate at which electrical energy is being used; *kilowatt-hours*, the amount of energy used at a given rate and for a given time.

Ohm's law, the relation between the amperes in a circuit, the pressure in volts, and the resistance in ohms. $I = \frac{V}{R}$.

CHAPTER XXVIII

RESISTANCE AND ELECTRICAL CIRCUITS

291. Resistance.—Resistance is the name given to that property of substances by virtue of which they hinder the flow of electricity through them. Let the temperature of the conducting substance, copper wire, for example, be kept constant. Then if its resistance is found to be 10 ohms when a current of 10 amp. flows through it with 100 volts applied, it will be found that if 20 volts are applied, the current is 2 amp. or its resistance is still 10 ohms. The resistance of a metallic conductor, under constant temperature, depends upon the nature of the metal, and the size of the conductor.

A copper wire 1 in. long and 0.001 in. in diameter has very nearly a resistance of an ohm at 65° C. Number 14 copper wire, the size used frequently in the drop-lamp cords, with a diameter of 0.064 in., will require 387 ft. to have a resistance of an ohm.

Electrical circuits may offer two classes of resistance, that of the metal conductors and that due to imperfect contact at points. All resistance lessens the energy of the flowing electricity by transforming some of it into heat, and the imperfect contact resistances are especially wasteful of energy in this way. A conductor may be carrying a current with little heating effect, but if a poor contact is present, a partly unscrewed toaster or electric iron plug, for example, the resistance at the loose contact becomes so great that the electrical energy transformed into heat may fuse the plug and the socket. More will be said concerning this type of resistance under the topic of the heating effect of the current.

292. Laws of Resistance.—If the temperature of a conductor is kept constant, the factors affecting its resistance can be expressed by the simple relation:

$$R = k\frac{L}{A},$$

where k is a factor whose value changes with the nature of the conductor, as iron, copper, etc., L is the length of the conductor and A the area of a cross-section. For circular wires, A varies directly as the diameter of the wire squared. For a given conductor the resistance varies *directly* as the length and *inversely* as the area of its cross-section.

The resistance of 1 ft. of No. 14 copper wire is 0.000248 ohm; the resistance of 100 ft. will be 0.0248 ohm.

$$0.000248 : x :: 1 : 100.$$

No. 14 copper wire has a diameter of 0.064 in. and No. 12 copper wire a diameter of 0.081 in. The resistance of equal lengths will be as:

$$R \text{ of No. } 14 : R \text{ of No. } 12 :: \overline{0.081}^2 : \overline{0.064}^2, \text{ or as } 16 : 10.$$

The resistance of nearly all conductors increases with increase of temperature. For the pure metals the increase is about 0.4 per cent for a rise of 1° C. A 100-ohm coil of wire, if its temperature is raised 100° C., will have a resistance of 140 ohms. The resistance of carbon decreases with the temperature. A carbon-lamp filament of a resistance of 250 ohms at room temperature has a resistance of 150 ohms when burning. Our present tungsten-filament lamps have a lower resistance cold than when hot. When the circuit is first closed, this lower resistance permits for an instant a larger current to flow and sometimes this larger current causes a fusion of the wire at some weak spot before the higher resistance, due to its temperature rise, can cut down the current.

The resistance of a conductor varies with the material of the conductor. The resistance of a given material of length 1 cm. and of 1 sq. cm. cross-section, that is, a cube 1 cm. on a side is called its "specific resistance." Conductors may be compared as to the effect of the kind of material on the resistance by knowing the specific resistance in ohms. For many purposes a more convenient way is to make a table of relative resistances, taking the material most used, copper, as the standard. The table below is of this kind.

Substance	Specific Resistance Relative to Copper
Copper	100
Silver	92
Aluminum	164
Pure iron	964
Pure water	2,650,000,000
Water, 5 per cent H_2SO_4	4,860,000
Glass at 20° C	9×10^{18}
Glass at 200° C	23×10^{12}
Alloys:	
Advance	2,800
Nichrome	2,600
Calorite	7,100

The table shows that silver would be the best low-resistance material were it not for its cost. Copper and aluminum are the most used for out-of-door circuits.

The development of high-resistance alloys has made possible the use of the many devices found in the home. If you examine the heating element in your electric toaster you will see it consists of a wire of fairly small diameter, or thin ribbon. The material is one of the high-resistance alloys, for example, calorite. Let us assume we had to use a copper conductor. The length of the conductor could not be increased very much without making the toaster too large. We will see later why a certain resistance is desirable but just now we will assume that the copper wire of approximately the same length must have the *same* resistance as the calorite. Its diameter then must be less. Applying the law of resistance, we find, since the resistance of the toaster is to be the same and the lengths of the wire the same, and assuming diameter of calorite wire is 1 mm., that

$1^2 : x^2 :: 7{,}100 : 100$, $x = 0.118$ mm., the diameter of the copper wire; and a copper wire of this small diameter would be so fragile that sudden jars would break it.

The resistance of the human body depends largely upon the dryness of the skin. It may vary from 10,000 to 300 ohms, and 2,500 ohms is usually taken as its resistance under normal conditions.

A circuit of 2 amp. traversing a vital part is fatal. The 110-volt circuit found in the home may prove fatal if good contact is made through the wet skin, but even a momentary contact produces a violent shock, and terrible muscular contractions may result from short circuiting the 110-volt circuit through the hands.

The effects of the current on the body are two: It acts upon the nerves, causing spasms, and it destroys the tissues either by burning or electrolysis, the blood becoming coagulated. To restore a person who has been made unconscious by an electric shock the same restoratives should be used as for a drowning person.

293. Insulators.—Materials which offer very high resistance to the flow of electricity are called "insulators" or "non-conductors." The various materials differ very much in their non-conducting properties. Some of the more common insulators are: glass, slate, marble, porcelain, mica, shellac, india rubber, ebonite, oils, dry wood, and paper. All insulators become better conductors on heating and their resistance changes with the voltage used.

294. Circuits.—An electric circuit must offer a continuous path for the current or there will be no flow. There are two

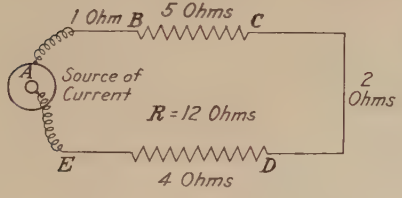


Fig. 178.—A series circuit.

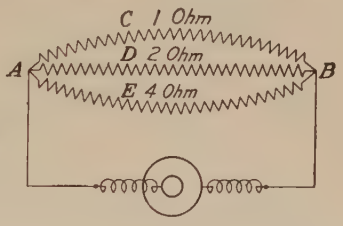


Fig. 179.—A divided or parallel circuit.

general types of electric circuits: The series and the divided or parallel circuits:

(*a*) *Series Circuit.*—If a number of electrical conductors are connected end to end the circuit so formed is called a "series circuit." The resistance of the circuit is equal to the sum of the resistances of the separate conductors. The figure represents a simple series circuit.

(*b*) *Divided or Parallel Circuit.*—If the circuit divides as shown in Fig. 179 the current will also be divided, a part flowing in each of the branches C, D, and E. The *relative* currents in each will be inversely proportional to the resistances. The current in C will be twice that flowing in D, and four times the current in E. The *total resistance of the circuit between A and B will be less than the resistance of any branch.* Let us apply Ohm's law to the whole circuit and to each branch. Assume the voltage of the circuit between A and B to be V, this will also be the voltage of each branch, and let a current I amp. flow from the source. At the juncture of the three circuits this current I will divide, a part flowing in each branch. Let I_C, I_D and I_E be the respective currents in the branches. We desire to know the resistance R between the points A and B when the resistance of each branch is R_C, R_D and R_E. From Ohm's law:

$I = \frac{V}{R}$, where I is the total current and R is the resistance sought.

Applying Ohm's law to each separate branch:

$$I_C = \frac{V}{R_C},$$

$$I_D = \frac{V}{R_D},$$

and

$$I_E = \frac{V}{R_E}.$$

But

$$I = I_C + I_D + I_E. \quad \text{Why?}$$

Then

$$\frac{V}{R} = \frac{V}{R_C} + \frac{V}{R_D} + \frac{V}{R_E}.$$

Dividing through by V:

$$\frac{1}{R} = \frac{1}{R_C} + \frac{1}{R_D} + \frac{1}{R_E}.$$

This equation shows that the resistance R depends *only* upon the resistances of the separate branches.

Clearing of fractions and solving for R:

$$R = \frac{R_C \times R_D \times R_E}{R_C \times R_D + R_D \times R_E + R_E \times R_C}.$$

Using the numerical values for the resistances of the branch circuits, we have

$$R = \frac{1 \times 2 \times 4}{1 \times 2 + 2 \times 4 + 4 \times 1} = \frac{8}{14} \text{ ohm.}$$

If the resistances of the branches had been all equal, say 6 ohms, then

$$R = \frac{6 \times 6 \times 6}{6 \times 6 + 6 \times 6 + 6 \times 6} = \frac{216}{108} = 2 \text{ ohms.}$$

We may generalize this special case, which is one frequently used, by stating that the resistance of n equal branches in parallel is $1/n$, of the resistance of one of the branches. In the above example,

$$n = 3 \text{ and } \frac{1}{n} \text{ or } \frac{1}{3} \text{ of } 6 = 2.$$

Illustrative Problems

1. The lower floor of a house of three rooms has a lighting circuit of three branches, one for each room; the resistances of the lamps in each room are 40,100 and 50 ohms. Find the resistance of the circuit.

$$R = \frac{40 \times 100 \times 50}{40 \times 100 + 100 \times 50 + 50 \times 40} = 18.1 \text{ ohms.}$$

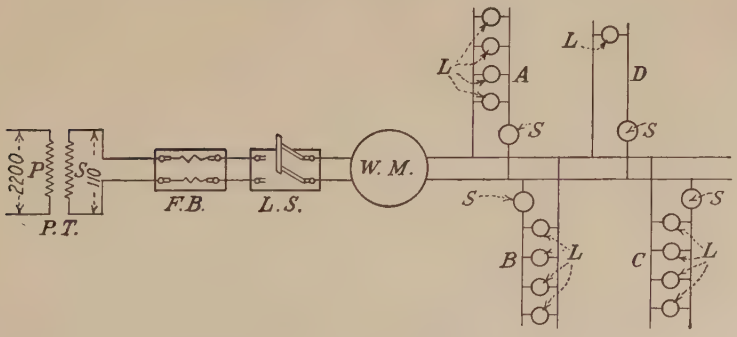


FIG. 180. — A typical house-lighting circuit.

295. Series and Parallel Bell Circuits.

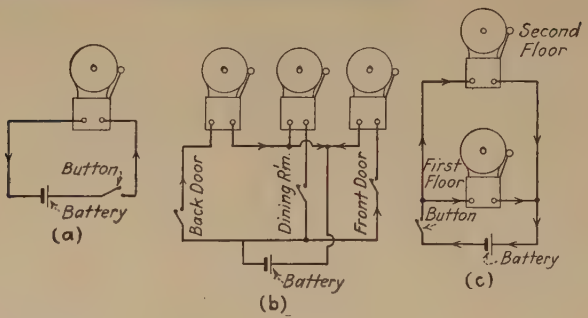


FIG. 181.

(*a*) Simple series-bell circuit. (*b*) Common three-bell house circuit. (*c*) Two-bell divided circuit, one push button.

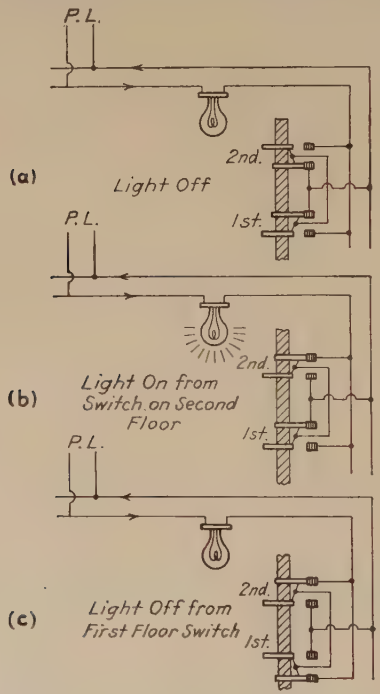


FIG. 182.—Lamp switches operated from either floor.

296. Lamp Switches.—It is generally more convenient to turn the light off or on from a wall switch rather than at the lamp.

In many rooms, it is desirable to be able to turn the lights off or on from two positions. Three-way switches are used for this service and the connections are shown for an upstairs lamp that can be controlled from either the first or second floors. The switches are shown out of proportion to the rest of the figure.

The lamp on the second floor (*a*) is turned off. In (*b*) the lamp has been turned on from the second-floor switch while in (*c*) the lamp has been turned off from the first-floor switch.

297. Current from a Single Lamp Socket.—It is not safe as a rule to take more than 600 watts from a lamp socket, and as the mains usually supply 110 to 120 volts, the current should not be over 5 amp. Electric appliances, such as toasters, irons, coffee percolators, heating pads, chafing dishes, vacuum cleaners, sewing-machine motors, etc., seldom require more than 500 watts and so may be connected to lamp sockets. It is a good rule to note the wattage or current values that will be found on nearly all household electric appliances before connecting them to the lighting circuit.

Study Exercises

1. What is the resistance of a coffee percolator taking 4.5 amp. on a 115-volt circuit?
2. How many kilowatt-hours are used in Exercise 1 if it takes 15 min. to make the coffee?
3. If the resistance of an electric iron is 20 ohms, how many feet of No. 14 copper wire would be required for the heating element?
4. If in Exercise 3 calorite of the same size were to be used, how many feet of it would be necessary?
5. What is the insulating material used to hold the heating element in your toaster?
6. A 20-cp. tungsten lamp takes 0.21 amp. on a 110-volt circuit. What is its resistance?
7. A sewing-machine motor takes 46 watts on a 115-volt circuit. What is the current and what is the resistance of the motor?
8. The No. 14 flexible cord used with an electric carpet sweeper is 15 ft. long. What is the resistance?
9. How many Christmas-tree electric lamps may be connected in series on a 120-volt circuit, if each lamp has such a resistance that 6 volts will give the maximum current a lamp can carry?

10. If the same number of lamps found necessary in Exercise 9 were connected parallel on the 120-volt circuit, what would happen?

11. Twin doorbells and one dining-room buzzer are in parallel. Each ringing device requires 5 amp. and has a resistance of 0.75 ohm and the connecting wires in each branch have a resistance of 0.25 ohm. What voltage must the battery supply?

12. If the devices in Exercise 11 were connected in series, what voltage would be necessary?

13. A large-sized flash lamp requires 4 volts and 16 watts. What is the resistance of the lamp?

14. The voltage in a home is 120. Two persons desire to iron and connect two irons, each rated at 5 amp., in series to one ordinary outlet plug. Explain their two mistakes.

15. If they had connected the two irons in Exercise 14 in parallel would they have made any mistake? What should they have done in order to use the two irons?

16. A seven-room house has three main divided circuits: One circuit will carry 500 watts, one 1,000 watts, and one 2,500 watts. The voltage is 110 volts. Find the current in each of the main branches when fully loaded and the total resistance of the three branches. If the entire load is on at one time what is the total current through the meter?

17. From your study in the laboratory of doorbell push buttons and lamp switches, what would be the danger to the push button of using 110 volts on the doorbell circuit assuming the bells to carry the same current in each case?

Some Suggested Laboratory Exercises

1. Study of the wiring circuits in a four-room house-model.
2. Set of various bell circuits.
3. Study of different types of plugs and switches.

REVIEW SUMMARY

The resistance of a conductor depends upon the nature of the material. It varies directly as the length of the conductor, and inversely as the area of the cross-section, or if a wire, inversely as the diameter squared.

$$R = k\frac{L}{A}.$$

The resistance of pure metals increases about 0.4 per cent for each degree Centigrade the temperature rises.

Specific resistance of pure metals increases about 0.4 per cent for each degree Centigrade the temperature rises. For purposes of comparison, the factor k is taken relative to copper as 100.

Metallic alloys of high specific resistance are used in household electrical appliances.

The resistance of the human body, a variable, 2,500 ohms being a representative value for a dry condition of the skin.

An electric current passing through the body acts on the nerves causing muscular contractions and it destroys the tissue either by burning or electrolysis. The blood is coagulated.

To restore a person suffering from a severe electric shock, the same restoratives are used as for a drowning person.

Insulators are high-resistance materials whose resistance depends upon the voltage applied.

An electric circuit is a closed path for the flow of electricity.

A series circuit is one in which all the conductors are connected end to end, furnishing one path for the flow of electricity.

A divided or parallel circuit is one in which the current has two or more paths.

The resistance of a divided circuit is always less than the resistance of the path of lowest resistance. It may be found from a relation in which $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$, etc.

The maximum current from a house-lighting plug is about 5 amp., 600 watts on a 110-volt circuit.

CHAPTER XXIX

HEATING EFFECTS OF THE ELECTRIC CURRENT

298. Heat and Resistance.—Work of various kinds may be done by a current, as chemical, magnetic, and thermal. A part of the electrical energy of the circuit is in each case transformed into other forms of energy. In this chapter the transformation of electrical energy into heat energy will be discussed.

Imagine a marble rolling along on a circular track. It would go on forever if there were no friction. Similarly a current once established in a loop of wire would continue to flow around it undiminished if the wire offered no resistance. The rolling marble lost its energy or motion by having it transformed into heat, owing to friction. Electricity in motion loses its energy, wholly or in part, by a transformation into heat, owing to the resistance of the circuit.

299. Heat in a Circuit.—Joule determined the factors upon which the *amount* of heat developed in a circuit depends. He found that the heat produced in a given conductor is proportional to:

1. Its resistance.
2. The square of the current.
3. The time the current flows.

If the current is given in amperes, the resistance in ohms, and the time in seconds, then H, the amount of heat in calories, may be found from the equation:

$$H = I^2Rt \times 0.24, \tag{1}$$

or since

$$R = \frac{V}{I}$$

$$H = (IV)t \times 0.24. \tag{2}$$

The 0.24 is a constant necessary to convert electrical units of energy into thermal units of energy in calories. The actual value of the constant is 0.2388.

Equation (1) shows that 1 amp. flowing through a resistance of 1 ohm for one sec. will produce 0.24 cal. Equation (2) shows that 1 watt will produce 0.24 cal. per second.

We buy electrical energy in kilowatt-hours and the amount of heat produced by 1 kw.-hr. is of interest. We may obtain it from Equation (2) by multiplying the watts IV by 1,000 and changing the time to seconds, 3,600:

$$H = IV \times 1{,}000 \times 3{,}600 \times 0.24$$
$$= 864{,}000 \text{ cal.} = 3{,}412 \text{ B.t.u.}$$

The heating effect of the electric current is not to be considered as heating the wire to a certain temperature, but it is the production in the wire of heat at a definite rate, so many calories per second. The temperature the wire attains depends upon a number of factors, chief of which is the nature of its surroundings. A rubber-covered wire will get much hotter than a similar bare wire. A bare wire in still air would be hotter than the same wire in a rapid current of air.

Most of the wires used about the home are rubber-covered and the safe carrying capacity, that is, the current which will not produce undue heating, is given in the table below. The flexible conductors used for irons, toasters, heaters, etc., are usually covered with asbestos, and, as the table shows, can safely carry a larger current.

	Safe Current in Amperes	
Copper Wire	Rubber Covered	Non-rubber Covered
No. 18	3	5
No. 16	6	8
No. 14	12	15
No. 12	17	23

Illustrative Problems

1. An electric-toaster cord of No. 14 wire is 3 ft. long, the current is 4 amp. on a 110-volt circuit. What part of the heat produced is developed in the cord per second?

The resistance of the cord is 0.00372 ohm.

$$H = 16 \times 0.00372 \times 1 \times 0.24 = 0.014 \text{ cal. per second.}$$

The resistance x of the toaster may be found from Ohm's law:

$$X + 0.00372 = {}^{11}0\!/\!_{4},\ X = 27.496 \text{ ohms.}$$

Heat appearing in the toaster:

$$H = 16 \times 27.492 \times 1 \times 0.24 = 105.57 \text{ cal. per second.}$$

2. How much heat per hour will be given out by a 500-watt electric heater?

$$H = 500 \times 3{,}600 \times 0.24$$
$$= 432{,}000 \text{ cal.}$$

or since the energy output was ½ kw.-hr., the heat liberated will be:

$$\frac{3{,}412}{2} = 1{,}706 \text{ B.t.u.}$$

300. Fuses.—As we have seen under the discussion of divided or parallel circuits, when more than one path is open to the flow of electricity, the current divides some going through each branch, the amount of current in each being inversely as the resistance of the branch.

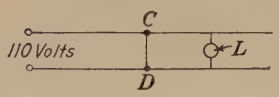


FIG. 183.—A simple lighting circuit, showing a "short circuit."

The figure shows a lamp on a 110-volt circuit. The connecting wires are No. 14 copper, easily carrying 10 amp. The lamp has a resistance of 55 ohms so 2 amp. are normally flowing. If, now, the lamp cord at C and D has some *bare* wire showing and these points are brought into contact by touching or by some metal touching both spots, a low-resistance circuit is established, say 1 ohm. The current coming to C divides, some going along CD and some through the lamp. The law of divided circuits tells us that the total resistance, R, is now not 55 ohms, but is:

$$\frac{1 \times 55}{1 + 55} \text{ or } 0.98 \text{ ohm.}$$

The current then flowing in the main circuit is not 2 amp. but 112 amp. The heat produced in the main circuit, varying as the current squared, is proportional to 112 squared as compared with 2 squared before the low-resistance path or *short circuit* was introduced. This increase would be apt to heat the wires to a red heat before they melted, starting a fire in the walls.

To prevent the danger, always present in short circuits, the main and all branch circuits are *fused*.

A fuse is a short piece of metal of a *low melting* point inserted in series with the line. The size of the fuse is so selected that it will carry the normal current without getting hot, but if a current 25 per cent larger is sent through the circuit this fuse will melt and open the circuit before the carrying wires become too hot. The figure illustrates type of fuse, the screw type most used in homes.

301. Electric Irons.—The electric iron is the most common of the electric appliances in use in the home. The heating element, which in the best modern irons can be easily replaced by a new element if necessary, usually consists of a grid of some high-resistance alloy placed inside a hollow iron casting.

FIG. 184.—Types of fuse.

FIG. 185.—Heating unit in an electric iron.

The heat is transmitted to the iron face by conduction and some is, of course, lost for ironing purposes, by radiation and convection from the top and sides of the iron. These losses are reduced by giving the iron a bright nickel finish and by placing insulating material in the top of the iron case. A determination of the ratio of the heat transmitted through the ironing face to the heat supplied by the current, shows that irons differ in what might be called their working efficiency. A study of eight irons of well-known makes showed that the poorest transmitted through the ironing face 64 per cent of the heat supplied, while the most efficient transmitted 85 per cent.

Some of the early irons were too light and required too much downward pressure on the part of the ironer. Irons weighing

Full length steel reinforcing rod.
Keeps handle always tight.
Large, comfortable, always cool wood handle.
Very flexible cord. Our own make
Wears longer.
Electrically welded steel handle supports
No screws or rivets to work loose.
Beautiful nickel finish, highly polished.
Attractive. Prevents rust.
Non-kink spring. Protects cord.
Cut-away nose. Makes ironing easier.
Perfectly balanced, does not tire arm or wrist.
Durable composition switch plug.
Always cool enough to handle
Pressure plate, machine milled.
Keeps heat in bottom of iron.
Hexegon cap nut which holds iron together.
Removable plug guard. Acts as
a guide for putting plug in position.
Bolts which clamp pressure plate, element
and bottom into practically one solid mass.
Nickel silver, non-corroding
round, removable contacts.
Riveted connections.
Cannot break or crack ribbon
Indestructible, patented, sheathed heating
element. Fool proof.
Genuine India mica insulation
Indestructible chromium-nickel ribbon resistance.
Bottom plate. Machine milled and
ground perfectly smooth on both sides.
Extra large ironing surface. Smooth as glass.
Perfect heat distribution over entire ironing surface.

FIG. 186.—Sectional view of an electric iron.

from 5.5 lb. to 6 lb. are satisfactory for general work and it seems very probable that 7-lb. irons may be even better.

The average iron takes from 400 to 600 watts, thus furnishing from 100 to 150 cal. per second. At 10 cts. per kilowatt-hour the cost per hour is from 4 to 6 cts., assuming that the current is on all the time. In practice, the current is usually on not more than half the time of the actual ironing. Sometimes an iron is used on a circuit of voltage different from that

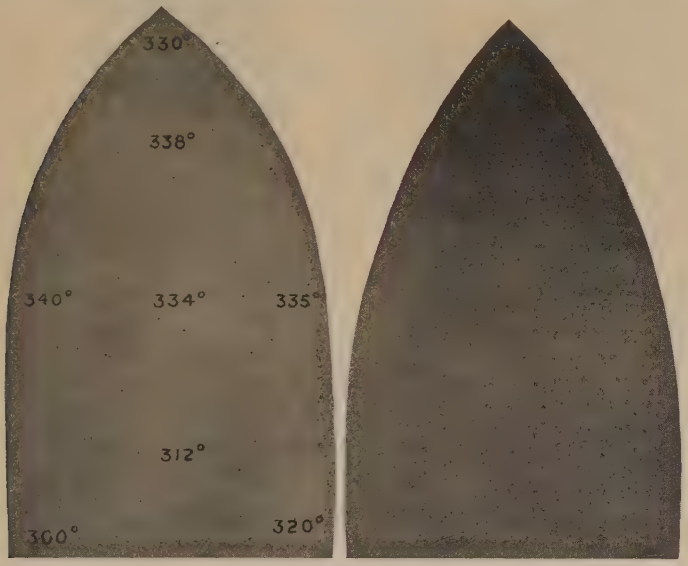
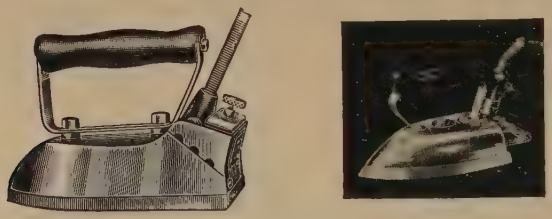


FIG. 187.—Showing distribution of heat on ironing face of two electric irons with temperature readings for one.

for which the iron was made. If the voltage difference is x per cent, then roughly the heat produced has changed by $2x$ per cent.

An even distribution of heat over the entire ironing surface, including the sharp point or nose, should give the most satisfactory results. If any part of the iron is to be hotter, it would seem as though it should be the nose as it is always first to meet the wet clothes. The illustrations indicate, by the varying intensities of the shading and also by the temperature readings, the relative distribution of heat in two irons.

Manufacturers have attempted to make the electric iron more satisfactory by various devices. The illustrations show two irons with control of the temperature. In Fig. 188(*a*) the temperature of the iron can be controlled between 200 and 600° F. by simply turning the screw at the end of the iron.



(*a*) (*b*)

FIG. 188.

The iron then automatically maintains the temperature for which it has been adjusted. In Fig. 188(*b*) one temperature is automatically maintained. Some irons have three-way switches by means of which the iron can be given a low, medium, or high temperature.

FIG. 189.—"Hubbell" plug and receptable.

302. Turning the Circuit On or Off.—In using any electric appliance on the ordinary lighting circuit, the appliance should *not* be connected until the wall plug has been screwed in and the wall switch turned on. When the circuit is to be *opened*, *pull* the connection from the appliance or from the wall socket *before* the wall switch is turned off. This will prevent the arcing at the switch or at the screw plug, which frequently results in a short circuit.

303. Electric Cooking.—The small electric appliances for light cooking, such as toasters, coffee percolators, chafing dishes, and disc stoves, are finding an increasing use in the home. The quickness with which the heat is available, the control of the temperature, the cleanliness of the operations, and the satisfaction of having the food hot and served as

wanted, far outweigh the slightly increased cost of operation. A few of the many such appliances now made are illustrated below. The cost data given are representative for the different types of the utensils and are based on a charge of 10 cts. a kilowatt-hour for electricity.

Toaster:

Amperes, 4.5; volts, 115; resistance, 25.5 ohms.

Heat produced per minute, 7,452 cal.

Average cost to toast 2 slices of bread, 0.14 cts.

Examine several toasters to see the method used to obtain a uniform distribution of heat over the entire surface of the slice of bread.

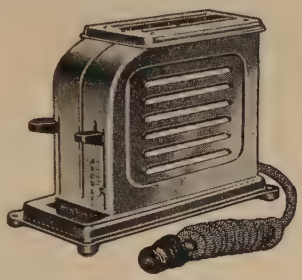


FIG. 190.—An automatic toaster.

Coffee Percolator:

Amperes, 4; volts, 115; resistance, 29 ohms.

Heat produced per minute, 6,900 cal.

Time to make six cups of medium strength coffee, 10 min.

Temperature of coffee when made, 170 to 180° F.

Cost of six cups, 0.8 cts.

FIG. 191.—Coffee percolator.

FIG. 192.—Immersion water heaters.

FIG. 193.—Disc stoves.

Immersion Water Heater:

Amperes, 4.3. Volts, 115.

Resistance, 27 ohms.

Heat produced per minute, 7,417 cal.

Time to boil 1 pt. water (65 to 212° F.), 11 min.

Cost to boil 1 pt. water, 1 ct.

Disc Stove:

Amperes, 5, volts, 115.
Heat produced per minute, 8,625 cal.
Resistance, 23 ohms.
Time to boil 1 pt. water, 15 min.
Cost to boil 1 qt. of water, 1.6 cts.

Electric Ranges:

There are many types of electric ranges now on the market. The illustration shows one type.

Obtaining heat from electricity is an expensive process as compared with getting the same amount of heat from gas or

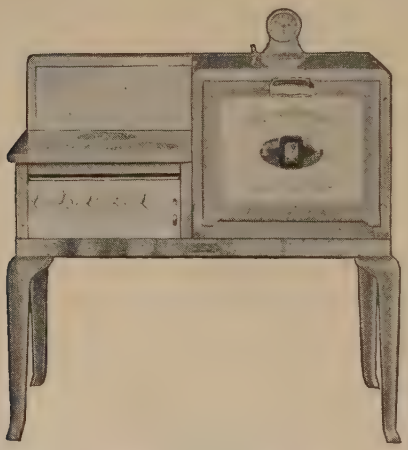


FIG. 194.—Electric range with automatic temperature control.

coal. It is only by decreasing the amount of heat that is ordinarily wasted that electric cooking can compete with the other types of stoves. If the electric stove, especially the oven, can be designed so as to utilize a greater percentage of the heat delivered, its increased efficiency may, partly at least, offset the lower fuel cost for gas and coal. The gas and coal ovens are exceedingly wasteful of the heat. The ordinary gas oven seldom uses for cooking more than 20 per cent of the heat and frequently wastes 95 per cent.

Convection and radiation are chiefly concerned in the heat losses from any oven. The radiation loss depends, as we have seen in Chap. XVI, upon the difference in temperature between the outside surface of the oven and that of the room, and upon the nature of the oven surface. Most ovens have a black outer surface which is, as a rule, not highly polished or glazed. These are ideal conditions for large radiation losses.

The convection losses depend upon the shape and position of the surfaces as well as upon the difference in temperature between the surface and the room. Air currents in the room also tend to increase these losses.

Gumear[1] has shown what these losses were in two commercial electric ovens and one gas oven:

	Calories Input	Calories Used	Per Cent of Efficiency
Electric oven No. 1	492	60.4	12.3
Electric oven No. 2	389	138.9	35.7
Experimental electric oven	452	205.5	45.5
Gas oven	1,940	106.6	5.5

The data were obtained by placing pans of water in the oven and turning the heat on full. The energy given to the water and that given by the fuel gave the efficiency.

Another test was made by putting pans of water in the ovens when the ovens were at a temperature of 150° C. and were maintained at this temperature throughout the test. The efficiencies of the ovens in the order given above were 26, 45, 64, and 10.8 per cent.

This test shows clearly that ovens are very wasteful of heat and that this waste can be greatly reduced, as indicated by the data on the experimental oven.

If we consider the factors that cause the loss of heat, the high temperature of the outside surface of the oven will be noted at once. Both the coal and the gas ovens in operation are good heaters for the kitchen, but bad heaters for the oven, and some of the electric ovens are still too much in the same class. The problem of outside temperature reduction is simply one of heat insulation. Poor conductors for heat are

[1] University of Missouri Bulletin Vol. 16 No. 27.

known and better insulated gas and electric ovens are in prospect.

Gumear points out that there are two kinds of oven cooking: one in which high temperatures are needed for comparatively short times, as in baking bread, cake and pastry; the other in which much lower temperatures are to be maintained for long periods, as in cooking meats, cereals, etc. These two kinds of cooking require ovens of different construction for economical use:

Gumear summarizes these needs as follows:

> The requirements for an electric oven for baking at high temperatures are: minimum heat capacity of the oven, a large heating unit to heat up the oven from room temperature, an automatic device to cut out this heating unit as soon as the oven reaches the desired value, smaller heating coils to maintain the oven at the proper temperature, a heating unit in the upper part of the oven, a baffle above the lower coils to distribute the heat, as small an oven as is practical for the size of the family using it, and from 2 to 4 in. of heat insulation. The requirements of an electric oven for cooking at the lower temperature are: from 3 to 4 in. of heat insulation, a simple device for automatically controlling the temperature, placing vessels of food directly on the heating units whenever possible, and a size of oven only large enough to contain the utensils used.

In roasting meats it was found that a preliminary searing on the hot plate before putting in the oven saved 1 kw.-hr.

304. Cost of Electric Cooking.—The cost of electric cooking can be stated only very approximately, as the kind of menus prepared, the efficiency of the electric range, and the care exercised by the operator in planning the meals and using the stove are all variable factors. One test of 7 days, doing all the cooking for a family of 5, the bread being purchased, gave an average of 5.4 kw.-hr. per day. This at a 2-ct. rate would mean about $3 per month. The heating of water for dish washing was not included. In the city of Seattle, the average monthly bill for 2,200 users of electric ranges was $3.65. This, at a rate of 2 cts. a kilowatt-hour, means that 182 kw.-hr. were used per month for cooking purposes.

305. Evaporation in Electric Cooking.—Experiments show that in roasting meats in an electric oven the loss due to evaporation ranges from 20 to 30 per cent, depending upon the temperature at which the meat is cooked. The losses in coal and gas ovens under similar conditions may go twice as high. Of course, this is not due to the kind of fuel used but to the fact that in the coal oven, and in the gas oven, especially, the juices are carried off continually by the current of air that is passing through the oven and around the meat. The higher temperature usually used is also a factor.

The loss in baking bread, biscuits, and cake differs with the temperature, decreasing as the temperature increases. Scientific cookery depends very largely upon knowing the exact temperature to be used and ability to maintain that temperature automatically. The electric range with its increasing ease of temperature control is well adapted to help put cooking on a scientific basis. The sometimes good luck and bad luck of the cook can be changed by definite rules for cooking which will insure uniform results.

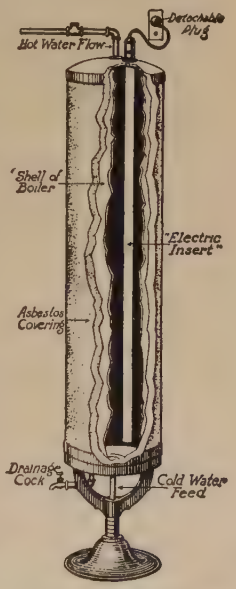


FIG. 195.—Immersion electric heater for hot water tank.

306. Electric Heating of Water. *Water Heating.*—Electric water heaters may be divided into two general types: the immersion heater and the hot plate heater.

The heating element in the immersion heater is placed in the liquid to be heated. This type of heater, neglecting the heat losses due to radiation and convection, is nearly 100 per cent efficient. All of the electrical energy is converted into heat energy and goes into heating the water, except the small fraction required to raise the temperature of the heating element itself. In practice, these heaters are from 85 to 98 per cent efficient, the lower values being due to the heat losses from the water container by radiation and convection. When

large quantities of water are needed at all times, the heating element should raise the temperature more or less slowly and the water container should be well insulated. If small quantities of hot water are demanded at irregular intervals, a heating element should be used that will raise the temperature quickly and then be cut out. The container in this case should be smaller and will need little or no insulation. Some of the electric coffee percolators and tea pots would be more efficient if the heating elements were made to carry a larger current.

The hot-plate water heater is of two types: One in which the heating element is on the *outside* of the bottom of the vessel and more or less permanently attached thereto. The other type in which the vessel is simply placed over the hot plate, gives a poorer contact between the vessel and the heating element. The efficiency of the first type may vary from 70 to 90 per cent and that of the second type 60 to 70 per cent. As in the case of the immersion type, the hot-plate heaters frequently have a much lower efficiency due to a small heating element, so the losses due to radiation and convection are relatively large.

In one rather extreme case, 1,000 g. of water placed in an *uncovered* pan on an 8-in. disc stove taking 550 watts, had not reached the boiling point in 50 min. The input of energy was 0.46 kw.-hr. or 397,400 cal.; the heat gained by the water was 90,000 cal. The radiation, convection, and evaporation losses amounted to 77 per cent.

307. Cost of Electric Water Heating.—If the efficiency of a given heater is approximately known, the table given below will give the kilowatt-hours consumed and the cost at 10 cts. a kilowatt-hour. One gallon of water may be taken as 8.3 lb.

Temperature Change	Efficiency of Electric Heater, Per Cent			
60 to 212° F.	100	90	80	60
Kilowatt-hours to raise 1 gal. of water to boiling:				
	0.37	0.41	0.46	0.61
	Cost 3.7 cts.	Cost 4.1 cts.	Cost 4.6 cts.	Cost 6.1 cts.

COMPARISON OF COST OF HEATING WATER

Cost of fuel	B.t.u.'s paid for	Assumed efficiency of conversion, per cent	B.t.u.'s gained by the water	Cost of fuel consumed, cents	Ratio of cost in terms of lowest
Coal, $7 per ton.....	100,000	10	1,000	2.91	8.8
Gas, $1 per 1,000 cu. ft.	3,333	30	1,000	.55	1.6
	2,000	50	1,000	.33	1.0
Electricity, 10 cts. per	1,666	60	1,000	4.90	15.0
kilowatt-hour.....	1,250	80	1,000	3.60	11.0

308. House Heating.—The heating of the home by electricity offers some very marked advantages over the usual methods. In an electric system, the control of the temperature at all times is easily possible and this control can be made automatic. The saving of labor and the gain in cleanliness both in the furnace room and the living rooms is very great. The system lends itself readily to placing the heat just where it is most needed. Cold corners or unusual heating conditions in the house can be satisfactorily treated. The fire risk is much reduced. Statistics show that about 1 per cent of the losses due to fire come from the use of electricity. The one great disadvantage of electric heating is the cost, and this will be discussed a little later.

309. Types of Electric Heating.—As in other heating systems the distribution of the heat may be by radiation, by convection, or by combinations of the two. *It should be kept constantly in mind that electric heaters of whatever type are equally efficient.* All the energy put into them is given out as useful heat. The various sources of loss in the other systems, as heat carried up the chimney, the convection and conduction losses in the pipes from furnace to room, are all absent. For every kilowatt-hour used the same amount of heat is produced and is available for warming the room.

(*a*) *Luminous Radiator.*—This type of heater consists of one or more tubular lamps mounted in a frame. The bright glow from the lamps and the rapidity with which it gives out

its heat, as well as its lightness, makes this type very desirable for portable use. Its two disadvantages are the liability to breakage by accidental knocks and the short life of the heater if used more or less continuously. A 24-hour per day use of one of these heaters for 4 months burned out both lamps. For occasional use, the lamps will, perhaps, last 3 or 4 years. The lamps in general take 250 watts each.

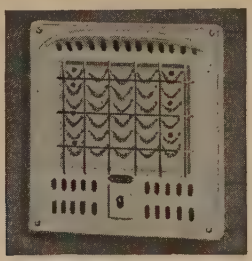


FIG. 196.—Luminous bulb radiator for use on lighting circuits

FIG. 197.—Radiant convector heater.

FIG. 198.—Convector type of heater.

(*b*) *Radiant Convectors.*—These heaters combine the advantages of the luminous radiator, with its cheerful, warm glow, with those of the convector type; the heating element warming the air directly by convection currents. The illustration shows one of the many different and attractive forms of this type. The concave mirror reflects the radiant heat into the room.

(*c*) *Convectors.*—In the convector heater the luminous feature is entirely absent and radiation is much less important in warming the room. Convection is the chief factor.

The heating element, which is usually one of the high-resistance alloys, as nichrome or calorite wire, is entirely enclosed. As it is used at a much lower temperature than that maintained in hot plates, etc., its life is much longer, perhaps 2 to 3 years for continuous night and day service. The control of the heat is effected by a switch giving usually full, half, and quarter heats.

(*d*) *Immersion Heaters.*—In recent years heating elements have been placed in the ordinary hot-water radiator. In some of the forms on the market there has been trouble due to the short life of the heating element. One type at least has appeared in which the radiator is filled with a heavy oil and it is claimed that the life of the heating element is much longer.

The use of a hot-water radiator type has some advantages and disadvantages. It is slow in raising the temperature of a room, easier to keep the room at a constant temperature, and more difficult to reduce the temperature quickly. It is usually more costly to install.

It is impossible in electric heating, as in any other system, to make a general statement of the amount of heat required based on the volume of the room. The shape of the room, the number, position, and size of the doors and windows, the outside walls, etc., all play a part. But to give some idea of the watts required we may say that 1 to 3 watts per cubic foot will usually be necessary. The wattage necessary for any room will not depend on the type of heater used.

310. Cost of Electric Heating.—In the typical room discussed in **Art. 169,** it was found that 22,785 B.t.u. per hour were necessary to heat the room under the conditions assumed. Since 1 kw.-hr. of electrical energy furnishes 3,412 B.t.u., this room will require 6.5 kw.-hr. The volume of the room was 2,520 cu. ft. This allows then about 2.5 watts per cubic foot. At 2 cts. per kilowatt-hour, the cost of heating this room by electricity would be 13 cts. per hour.

A rather careful experiment of the cost of heating a six-room house for 6 weeks by electricity and for 6 weeks by a hot-air furnace, under nearly equal conditions of outside and inside temperatures, showed that the electrical heat cost 3.46 times

that of the coal heat. The coal cost $7.75 a ton and the electrical energy was bought at 1 ct. a kilowatt-hour. With electrical energy at 0.29 ct. per kilowatt-hour the cost of the two types of heating would have been equal.

Loew[1] has shown from his extensive study of the cost of electric heating that the number of kilowatt-hours required per month per 1,000 cu. feet per degree difference in temperature per degree relative humidity may be found by taking the product of these factors and multiplying it by 0.165.

Applying this rule to a house of 22,000 cu. ft., assuming an average outside temperature for the year of 45°, average inside temperature 68°, average humidity 40 per cent, the total kilowatt-hours required will be:

$$22{,}000 \times (68-45) \times 0.40 \times 12 \times 0.165 = 40{,}075$$

At 1 ct. a kilowatt-hour, the cost of heating is $400.75.

Study Exercises

1. A coffee percolator takes 400 watts. It is used for 10 min. How many calories are given to the water? Heat losses are neglected.

2. A bathroom is heated by one 500-watt lamp for 45 min. Assuming all the energy goes into heat, how many calories are given to the room?

3. A small immersion water heater takes 250 watts. Allowing a loss of 20 per cent, how long will it take to heat 1,000 g., 1 qt. approximately, of water from 15° C. to 100° C.?

4. A sewing room requires 4,000 B.t.u. per hour to heat comfortably. Find the wattage necessary to heat the room by electricity.

5. If 2 watts are required to heat each cubic foot of air in a room under given conditions, how much heat per hour is put into a room 10 by 10 by 8 ft.?

6. An electric foot warmer takes 0.60 amp. on a 115-volt circuit. What heat per second is being furnished?

7. A certain gas oven uses 15 per cent of the heat in the gas, taking 15 cu. ft. in 30 min. and 10 cu. ft. in 60 min., to do some baking. How many kilowatt-hours of electricity would be required to do the same baking in an electric oven that utilized 50 per cent of the heat?

8. A disc stove has a resistance of 20 ohms and takes 6 amp. How much heat is produced in 30 min.?

9. A circuit in the kitchen has a 5-amp. fuse. What will happen if a toaster and a coffee percolator are connected to the kitchen circuit?

[1] *Univ. Wash. Eng. Expt. Sta. Bull.* 15.

10. What is the objection to replacing a 5-amp. fuse with a 20-amp. fuse in a circuit?

11. Sometimes on a cold night a 25-watt tungsten lamp has been placed in a bed under the clothes. What is the danger?

Some Suggested Laboratory Exercises

1. Heat produced by two different types of immersion heaters. Efficiency.

2. Study of the distribution of temperature on the ironing face of flat irons.

3. Study of electric appliances, toasters, coffee percolators, disc stoves, etc.

4. Study of electric heaters of different types.

REVIEW SUMMARY

In all electrical circuits some of the electrical energy is transformed into heat.

The heat thus transformed can be found from:

$$H = I^2Rt \times 0.24 = \text{cal.} \quad H = IVt \times 0.24 = \text{cal.}$$

One kilowatt-hour of electrical energy all transformed into heat furnishes 3,412 B.t.u.

Fuses are low melting point conductors inserted in series in a circuit to protect the circuit from excessive heating due to a short circuit.

Discussion and description of small heating devices.

Electric cooking costs may be comparable with those of gas cooking.

Electric water heating is more expensive than gas or coal water heating.

Electric house heating is more expensive than heating by coal.

All electric heaters have the same efficiency; that is, for each kilowatt-hour used the same amount of heat is obtained.

CHAPTER XXX

MAGNETIC EFFECT OF A CURRENT

311. Magnetism.—The main facts about magnetism will be reviewed briefly. A magnetized bar of steel has acquired the property of attracting iron, steel and a few other substances. A magnetized bar, a magnet, has its magnetism concentrated at or near its ends, called "poles." The magnetism at each end is different. If we suspend a magnet so that it hangs in a horizontal plane, it is found that one end will always point to the north; let us call this end the north pole, and the other end will point to the south, the south pole. Now if two north or

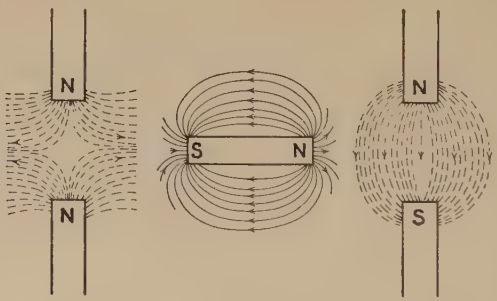


FIG. 199.—Magnetic fields.

two south poles are brought near each other they are *repelled*, while if a north and a south pole are brought near each other they are attracted. Since attraction or repulsion takes place when the magnets are not in contact, we say there is a magnetic field around each pole. Faraday called the region around a magnetic field, a "field of force" and imagined this field to be filled with lines of force. Figure 199 illustrates the field of force and the imaginary lines of force as shown by iron filings.

312. Physiological Action of Magnetism.—Magnetism produces no physiological action of any kind. The use of magnets in hair brushes, belts or rings is of no value whatever.

313. Oersted's Discovery.—A copper wire with no current in it is unaffected when placed in a constant magnetic field. But when a current is flowing in it, the wire acquires magnetic properties, and if placed in a magnetic field, will be attracted or repelled. A magnet or another wire carrying a current, brought near this wire, will be either attracted or repelled.

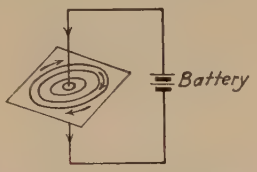


FIG. 200.—Showing lines of force around a wire carrying a current.

In Fig. 200 is shown a straight wire carrying a current and several of the imaginary lines of force around a wire due to the current. The arrows indicate the direction of the current and of the magnetic field.

314. The Electromagnet.—If a wire, wound on a bar of soft iron, is connected to a source of electricity, the field of force due to the current in the wire magnetizes the iron.

The figure shows a single coil of wire and the polarity of the iron bar. If the current should flow in the opposite direction in the coil, the poles in the bar would be reversed. A soft iron bar will lose its magnetism when the current ceases to flow in the wire.

FIG. 201.—Bar of iron made a magnet by the current flowing in the coil of wire.

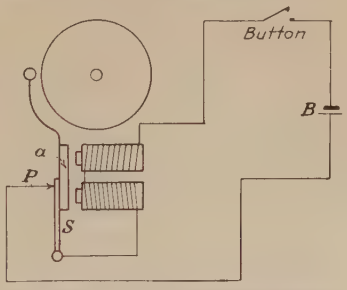


FIG. 202.—The electro-magnets in the doorbell.

The electric doorbell is one of the most familiar uses of an electromagnet. In order that the bell may continue to ring as long as the circuit is closed, the bell is fitted with a device called the interrupter or vibrator. A simple bell circuit is

shown in Figure 202. When the bell button is pushed the current flowing in the electromagnets magnetizes the iron cores and they attract the soft iron armature a, pulling it away from P, thus breaking the circuit. The iron cores of the electromagnets lose their magnetism and the armature is pulled back against P by the spring, S, again closing the circuit through P. The operation is then repeated.

315. The Side Push of a Magnetic Field.—If AB in the figure is a wire, part of an electric circuit carrying an electric current in the direction indicated by the arrows, then the wire is pushed sidewise, away from the reader, by the force reactions due to the two fields of force, that of the magnet and that of the wire. If the current should have its direction changed, flowing from A to B, or if the magnet is reversed, then the push is toward the reader.

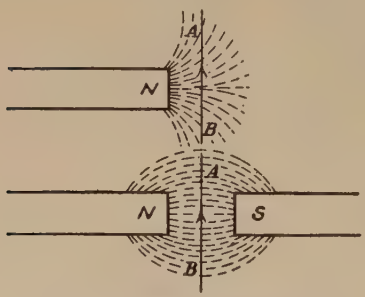


FIG. 203.—Push of a magnetic field on a wire carrying a current.

A wire carrying a current when placed in a field of force at right angles to the lines of force of the field, is acted upon by a force which is at right angles to the lines of force and to the wire. This side push on the wire finds immediate application in the direct current motor.

316. Direct-current Motor.—The figure represents the simplest type of a motor, a single coil of wire AB connected to the separate halves of a metal cylinder, called a "commutator." Each half is insulated from the other and is in contact with the brushes EF, which are connected to a source of electricity. Let the coil be at rest in the position shown when the current is set flowing in the direction indicated by the arrows. As we have seen, the wire on the A and B sides of the coil will be acted upon by the forces tending to move them at right angles to the magnetic field due to the magnets. A will be pushed *upward* and B *downward*, so the coil will rotate, due to the forces acting, until A and B are in the vertical

position. The forces producing the rotation are then zero in value. The inertia of the moving coil, however, keeps it moving until it is out of the vertical position. The commutator has rotated with the coil, so now the brush E is connected to the part C' and the brush F is connected to the part C; that is, the direction of the current in the coil is reversed. The B side of the coil is now on the left and the A side on the right. This reversal of the coil and the direction of the current will cause the forces acting upon A and B to continue the rotation of the coil in the *same direction*. Hence a steady continuous current from the source S will produce a continuous rotation.

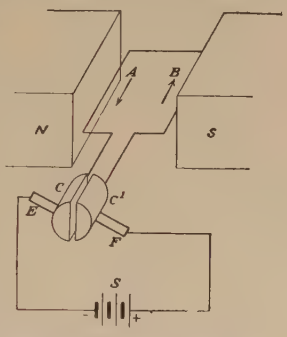


FIG. 204.—Simple direct current motor.

The commercial motor is similar to the machine described above, but modified in detail. There are many similar loops of wire equally spaced on an iron core and the half-cylinders of the commutator are cut up into narrow strips, insulated from each other, so that the ends of each loop can be connected to its pair of segments. Nearly all the motors used in the home on sweepers, washing machines, etc., are direct current motors, series wound, thus permitting their use on either direct or alternating currents.

It should be kept in mind that the motor is simply another of the many devices for the transforming of energy. The energy of the flowing electricity is partly transformed into the mechanical energy of the revolving armature. In the larger sizes, electric motors are highly efficient, about 85 per cent of the input appearing in the usable energy. In the smaller sizes, found usually in the home, they are not so efficient.

REVIEW SUMMARY

Bars of iron, steel, and a few other substances, when magnetized, have the property of attracting the same substances that are capable of being magnetized.

A magnet has its magnetism concentrated near its ends, called poles.

A magnet has two unlike poles, called a north pole and a south pole.

Like magnetic poles repel each other; unlike poles attract.

The magnetic effect extends into the region around the magnet, called a magnetic field.

Magnetism produces no known effects on the human body.

Oersted discovered that a wire carrying a current had a magnetic field around it and could be attracted or repelled by a magnet or another wire carrying a current.

An electromagnet consists of a core of soft iron on which is wound coils of wire. A current flowing in the wire makes the iron core behave like a bar magnet.

A wire carrying a current when put into a magnetic field at right angles to the field experiences a push or force tending to take it out of the field.

The electric motor is a direct application of this fact. Electric motors are devices for transforming electrical energy into mechanical energy.

CHAPTER XXXI

CHEMICAL EFFECTS

317. Chemical Effect.—When electricity passes through *certain liquids*, chemical changes may be detected at the places where it enters and leaves the liquid. Faraday called this chemical decomposition "electrolysis"; the conducting liquid, the "electrolyte"; the pole at which the electricity enters the liquid, the "anode," and the plate at which it leaves, the "cathode."

We may obtain a general idea of the phenomena by considering a single case. Let a glass vessel contain a solution of $CuSO_4$ with two copper plates for taking the electricity into and out of the vessel. After the electricity has been passing through the liquid for some time, it is found that the plate by which it leaves the vessel has received copper, while the other plate has lost copper. The passage of the current broke up the $CuSO_4$ into Cu and SO_4, the former, traveling in the direction of the moving electricity, was deposited on the cathode plate, while the SO_4 united with some of the copper of the anode plate to form $CuSO_4$.

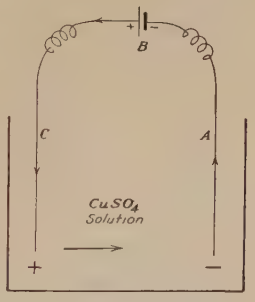


FIG. 205.—Electrolysis of copper sulphate.

The simplest explanation of electrolysis is that given by the ionic theory. All electrolytes, as solutions of $CuSO_4$, NaCl, HCl, etc., have some of their molecules split up into constituent radicals, as $CuSO_4$ into Cu and SO_4, NaCl into Na and Cl, etc. That these radicals do not act at once on the solvent water, and, as in the case of Na, form NaOH, is explained by their carrying charges of electricity which in some way prevents chemical action. The Cu, Na, H, etc., carry *plus* charges and

the SO_4, Cl, etc., carry *negative* charges. These dissociated charged radicals are called ions. The positive ions tend to move with the current toward the cathode plate, while the negative ions tend to move against the current toward the anode plate.

318. Faraday's Laws.—Faraday was the first to determine the quantitative relations between the amount of ions deposited and the quantity of electricity flowing through the electrolyte.

The mass of any ion deposited from an electrolyte is proportional to the quantity of electricity passed through the electrolyte. If M is the mass of ions deposited, and q is the quantity of electricity (q equals the current in amperes times the time in seconds), we have

$$M \propto q, \text{ or } M \propto It \text{ and } M = kIt$$

If I and t are unity, $k = M$. The factor k is called the electrochemical equivalent of the substance and is, evidently, the mass deposited in unit time by unit current.

Imagine a number of electrolytic cells, each with a different electrolyte, connected so that the same current goes through each. Let the electrolytes be HCl, $AgNO_3$, $CuSO_4$, and $NiSO_4$. If the current deposits one gram of H, it is found that 107.9 g. of silver, 31.78 g. of copper, and 58.68 g. of nickel are deposited from their respective solutions. These numbers are proportional to the chemical equivalents of the substances. Faraday's second law of electrolysis based on this fact states that the mass of a substance deposited by a current per unit of time is proportional to its chemical equivalent.

By experiment it has been found that 1 amp. flowing for 1 sec. through a solution of $AgNO_3$ will deposit 0.001118 g. of silver. The mass of copper deposited in 1 sec. by 1 amp. will, from Faraday's second law, be $31.78/107.9 \times 0.001118$ or 0.0003271 g.

The electro-chemical equivalents of a few substances are given below:

Substance	Electrochemical Equivalent, Grams per Coulomb
Silver	0.001118
Copper	0.0003271
Nickel	0.000304

319. Application of Electrolysis.—Many of the utensils used in the home are plated. The plated knives, forks and spoons, as distinguished from the sterling silver articles, are made of white metal, Britannia metal or brass, and given a thin or thick deposit of silver by electrolysis. The many nickel utensils, as tea kettles, metallic lamps, stove pokers, etc., are simply iron, brass or copper articles with an electrolytic deposit of nickel.

An electrolytic method for cleaning tarnished silver has come into use in recent years and has been found very satisfactory. In a granite dish is placed a piece of sheet aluminum and on this is piled the silver to be cleaned. The electrolyte, which is made by adding 1 teaspoonful each of washing soda and table salt to 1 qt. of water, is poured boiling hot into the dish. After about a minute, the silverware may be removed from the electrolyte. The arrangement described is an electrolytic cell with the electricity flowing from the aluminum to the silver. The tarnish, silver sulphide, is slightly soluble and a small number of silver and sulphide ions are present in solution, so the silver ions will give up their positive charges of electricity and be deposited on the silver plate as metallic silver. The chemical reactions taking place in the cell are as follows:

1. $Na_2CO_3 + 2H_2O = H_2 + 2NaOH + CO_3$.

Aluminum will displace hydrogen from a boiling solution of an alkali.

2. $Al + 3NaOH = Na_3AlO_3 + 3H$.

The hydrogen supplied by this reaction reduces the silver sulphide.

3. $Ag_2S + 2H = H_2S + 2Ag$.

Illustrative Problem

1. Let us assume a knife blade has a surface area of 65 sq. cm. and that it is desired to deposit on it a coating of silver 0.001 cm. thick. The volume of the silver will be 0.065 c.c. and the density of silver being 10.5, the mass to be deposited will be 0.6825 g. If a current of 0.5 amp. is flowing through a solution of silver nitrate, the knife being the cathode, how long would it take to deposit the silver?

From Faraday's law:

$$M = Itk;$$

Hence

$$0.6825 = 0.5 \times 0.001118 \times t.$$
$$t = 1{,}220.0 \text{ sec.} = 20.3+ \text{ min.}$$

320. Electric Cells.—We are all familiar with the dry battery used for doorbell circuits and in flashlights. The term "battery" should preferably be applied to two or more electric cells. An electric cell is a device for converting chemical energy into electrical energy. The essentials of any cell are two unlike conducting plates and a liquid conductor whose action on one of the plates is very much greater than on the other. Chemists know that acids act more vigorously upon some metals than upon others, and experiments have shown that the highest electrical pressures are produced when the two plates of a cell are two substances upon which the chemical action of the electrolyte is as different as possible. It is owing to this fact that the plates of nearly all cells are zinc and carbon or copper.

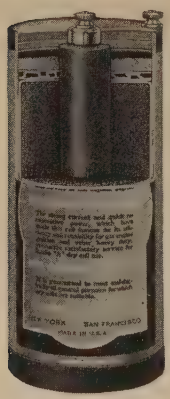


FIG. 206.—Dry cell.

In an electrolytic cell, the chemical action was produced by passing an electric current through the cell. In an electric cell, the chemical action takes place, in general, when the two plates are connected by an outside conductor. This chemical action furnishes the energy. The zinc may be regarded as the fuel, which, disappearing as metallic zinc, is the source of the energy. This energy sets up a difference of electrical pressure between the two plates and thus makes possible a flow of electricity through the circuit.

The dry cell, the only one we shall describe, consists of a zinc container in the center of which is a rod of carbon. Around this carbon is a porous mass consisting of granular carbon, coarse manganese dioxide, MnO_2, and a saturated *solution* of ammonium chloride. The cell is sealed. The voltage of such a cell is 1.5 volts and its resistance, which varies with the size and exact method of construction, may be taken as

approximately $\frac{1}{10}$ ohm for the cell used for doorbell circuits. Hence the maximum current possible would be 15 amp.

320*a*. Polarization of a Dry Cell.—The main chemical action in a dry cell may be represented by the equation:

$$Zn + 2NH_4Cl = ZnCl_2 + 2NH_3 + H_2.$$

The hydrogen goes to the carbon plate and soon the plate is covered and surrounded by hydrogen gas. The effect of this gas is twofold: (1) it prevents good contact between the plate and the electrolyte, thus *increasing* the resistance of the cell; and (2) the hydrogen gives rise to an electrical pressure which is in opposition to the original pressure. The effect of this is to *decrease* the pressure causing the flow of electricity. If the cell is used continuously for some time, this opposite pressure finally equals the other and no current will flow. The cell is said to be polarized.

The polarization being due to the hydrogen gas on and around the copper plate can be overcome by removing the hydrogen gas. This is accomplished by the manganese dioxide as shown by the equation:

$$2H_2 + 3MnO_2 = Mn_3O_4 + 2H_2O$$

The manganese dioxide is, however, a slow depolarizer, so the dry cell must be left on open circuit in order for depolarization to be complete. After a rest, the cell is ready to produce a current again.

This cell then is adapted for intermittent service such as doorbells, telephones, flashlights, and radio.

The useful life of a dry cell depends upon its size, the amount of current taken from it, and the frequency of the service. In ordinary home service for doorbells, they may last from a year to two years, for flashlights, a month or more, in radios 6 months or more. They cannot be renewed but must be replaced by new cells.

321. Connections for Cells.—Cells are connected to form a battery in one of two ways usually. In *series*, where the carbon of one cell is connected to the zinc of the next cell and so on as shown in Fig. 207(*a*). In *parallel*, where all the carbon

plates are connected, and all the zinc plates are connected, thus forming one large cell, as shown in Fig. 207(*b*).

The voltage and resistance of n cells connected *in series* is the sum of the separate voltages and resistances. Assuming the cells are all similar, and applying Ohm's law to find the current flowing in an external resistance of R ohms, we have:

$$I = \frac{nV}{R + nr}.$$

If n similar cells are connected *in parallel* we find for the current flowing through an external resistance of R ohms:

$$I = \frac{V}{R + \frac{r}{n}}.$$

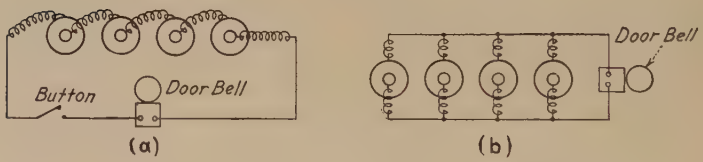


FIG. 207.—(*a*) Cells in series; (*b*) cells in parallel.

When the external resistance R is large compared with the resistance of the cell r the maximum current will be obtained by a series connection. But if the internal resistance of the cells is large in comparison to the external resistance, the maximum current will be obtained by a parallel connection.

Illustrative Problems

1. Five dry cells, each of voltage 1.5 and internal resistance $\frac{1}{10}$ ohm are connected to a circuit of resistance 15 ohms. Find which kind of connection will give the maximum current.

Series

$$I = \frac{5 \times 1.5}{15 + 0.5} = 0.483 \text{ amp.}$$

Parallel

$$I = \frac{1.5}{15 + \frac{0.1}{5}} = 0.0998 \text{ amp.}$$

2. Five dry cells as above are to furnish a current for an external resistance of 0.05 ohm.

In series,

$$I = \frac{5 \times 1.5}{0.05 + 0.5} = 13.6 \text{ amp.}$$

In parallel,

$$I = \frac{1.5}{0.05 + \frac{0.1}{5}} = 21.4 \text{ amp.}$$

REVIEW SUMMARY

Some liquids are conductors of electricity and are decomposed by the passage of a current through them.

This chemical decomposition is called "electrolysis," and such liquids are called "electrolytes."

One of the products of decomposition goes to the positive plate and the other goes to the negative plate.

Faraday states that the mass of the substance deposited is proportional to the current, the time, and a constant of the liquid called the electrochemical equivalent.

The electrochemical equivalent is equal to the mass deposited in 1 sec. by a current of 1 amp. For silver this is 0.001118 g.

Electric cells are devices for converting chemical energy into electrical energy.

The dry cell consists of a zinc cylinder with a carbon rod in the center. Granular carbon manganese dioxide and a saturated solution of ammonium chloride are placed around the carbon rod. The voltage is 1.5 volts and the resistance varies with the size and construction of the cell.

The deposition of hydrogen gas on the carbon plate causes polarization.

The effect of polarization is to decrease the current due to a higher resistance and the production of a voltage opposing the original voltage. The manganese dioxide, working slowly, removes the hydrogen by forming water, H_2O. The cell, when depolarized, is in a condition to deliver a current again.

Cells may be connected in series or in parallel. When the external resistance is large in comparison with the resistance of the cells, a series connection gives the higher current. When the external resistance is small, then a parallel connection gives the larger current. Doorbell batteries are connected generally in series.

CHAPTER XXXII

INDUCTION EFFECTS OF THE CURRENT

322. Induction.—In 1831, Faraday discovered that the *starting* and *stopping* of the current in an electric circuit produced a *momentary* current in another closed circuit if in its immediate neighborhood. This momentary current produced in this way is known as "induced current" and the voltage which causes the flow of the *induced* current is called the "induced voltage."

Figure 208 represents an electric circuit containing a source of electricity, the battery B, an adjustable resistance R

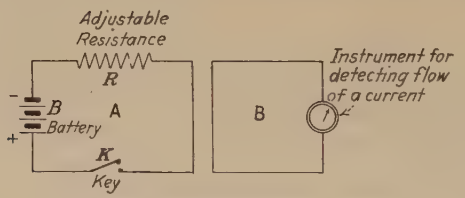


Fig. 208.—Electromagnetic induction.

a key, and an instrument for showing the presence of any current flowing in the circuit. The circuit A is generally called the *primary* circuit, and its current and voltage the primary current and primary voltage, while the term *secondary* is applied to the corresponding factors of B.

A further study of the conditions under which the secondary current is produced will show that there is a current induced in B:

(a) When the current is started or stopped in A.

(b) When the magnitude of the current in A is changed.

(c) When the distance between A and B is changed during the flow of current in A.

The circuit in the primary is surrounded, as we have seen, by a magnetic field which changes in value with respect to the primary circuit whenever any of the conditions enumerated above are changed. This fact would indicate that the *induced* voltage in the secondary circuit is a result of *the changing magnetic field in the primary circuit.* We can test this conclusion at once, for if the magnetic field is the cause of the induced voltage, a bar magnet with its field of force suddenly brought up to the secondary circuit or removed from it, should produce induced voltage in B. Experiment shows that induction effects do result under these conditions.

Let the north pole of a magnet be suddenly thrust into a coil of wire. There is produced a momentary current in the coil. When the magnet is removed again there is a momentary current but it is flowing in an opposite direction in the coil. If the south pole is thrust in a current is induced which flows in the same direction as did the current when the north pole was taken out. Removal of the south pole gives a current flowing in the same direction as that produced by thrusting the north pole in.

All these experiments show that the induced voltage and the accompanying induced current are due to a *change in the number* of *lines of force* cutting the coil.

323. Magnitude of the Induced Voltage.—Experiments also very clearly indicate that the *magnitude* of the induced voltage depends upon the *number of lines of force cut in a unit of time.* Let N equal the number of lines of force entering or leaving a closed circuit, or the number of lines of force being cut by a closed conductor in t seconds. Then the induced voltage is proportional to N/t.

324. Direction of the Induced Current.—If the current in Fig. 208 is flowing in the circuit as it is *brought up* to B, the induced current flows in the *opposite* direction to that in the primary. If the primary circuit is *removed* from the secondary circuit, the current in the secondary flows in the *same* direction as that in the primary.

An examination of the conditions under which the inductions above have taken place shows that the force reactions

between the primary and secondary *fields of force* are such as to require the *expenditure of energy* to bring about the induction. The energy, then, in the secondary circuit comes from the expenditure of a *greater* amount of energy than would be required if no induction took place.

We might have deduced this fact from principle of the conservation of energy, for this principle tells us that since an electric current has energy, such a current can be produced only by the expenditure of energy in some form, in this case in the extra work done.

325. Direct- and Alternating-current Generators.—Electric generators are of two kinds, direct-current generators and alternating-current generators. Direct currents, like water and gas in pipes, flow in one direction in the circuit. Alternating currents (abbreviated to a.c.) flow first in one direction, then in the opposite direction. These changes in direction take place many times each second. In many commercial circuits the current changes direction 120 times each second and such a current is known as a 60-cycle alternating current. All such generators are mechanical devices to enable one to move wires *across* the lines of force, to cut the lines, and, hence, to produce, as we have seen, an induced voltage in the circuit.

The essentials of a generator are an electromagnet with the two poles separated and between these poles in the magnetic field a coil of wire which can be rotated. Figure 209 omits the electromagnet showing simply the magnetic field and the loop or coil of wire. One end of the loop is connected to a metal ring fastened to the shaft which rotates the loop. The other end of the loop is fastened to another metal ring on this shaft, the two rings being insulated from each other. Brushes resting on each ring carry the current to the outside circuit.

It will be seen that when the plane of the loop is vertical *a* the wires are moving parallel to the lines of force and so no lines are being cut. At this instant the voltage is zero. Let us follow the upper side of the loop in *a* through a complete revolution. As the upper side of the loop rotates with a uniform velocity through 90 deg. from *a* to the *b* position, this

side of the loop is cutting lines of force at an *increasing* rate. The induced voltage has grown from zero to a maximum as is shown in *f*. When the loop makes the next 90 deg. rotation from *b* to *c* the rate of cutting lines of force is *decreasing* for at *c* the rate is zero again. The induced voltage has changed from a maximum to zero. From the *c* to the *d* position the rate of cutting lines is again *increasing*, but the direction of cutting of the lines is *opposite* to that in the first 180-deg.

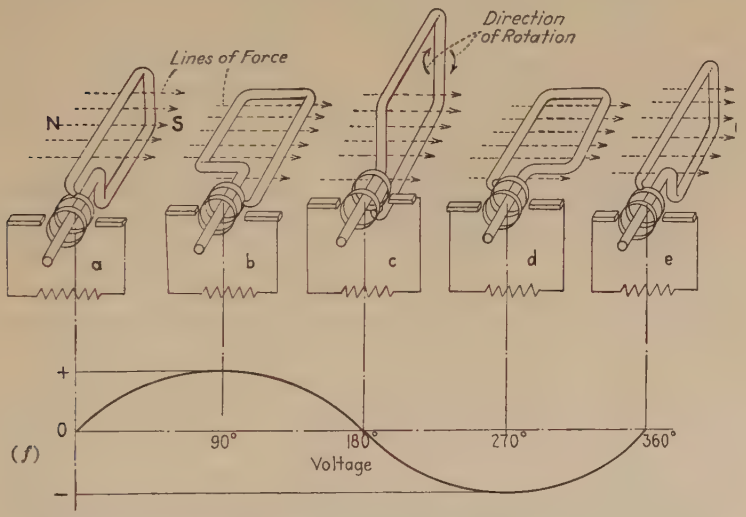


FIG. 209.—Showing the changes in the induced voltage in an alternating-current generator.

rotation. This results in an induced voltage growing from zero to a maximum but in the opposite direction. The last 90-deg. rotation from *d* to *c* will evidently give simply a decrease in the voltage as shown in *f*. The induced voltage then changes its direction twice in each complete revolution of the coil and the current does also. Hence this type of generator gives an alternating current.

326. The Transformer.—The transformer is a device for transfering electrical energy from one electrical circuit to another with which it is not connected. Its action is based on the induction phenomena we have been studying. The

figure represents a simple transformer. On a ring of soft iron are wound two coils of wire A and B. The A coil is connected to an alternating-current generator or circuit As a result of the changing current in A there will be a changing magnetic field and its lines of force will thread through the coil B. This we saw was the condition for inducing a voltage in a near by closed circuit. Coil B if connected to a lamp, for example, will have an induced current which may operate the lamp.

Transformers, like the machines we studied in mechanics, cannot transfer from one circuit to another more energy than they receive. But they do, somewhat as machines enabled us to control the factors of force and distance, enable us to control the magnitude of the induced voltage and current.

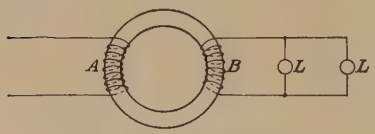


FIG. 210.—Simple transformer.

If the induced voltage is higher than the applied voltage such transformers are called "step-up" transformers and if the induced voltage is less, they are called "step-down" transformers.

If coil A has one turn of wire, the voltage applied being 1 volt, and coil B has ten turns of wire, then the voltage in B will be 10 volts. Around A was a magnetic field with a certain number of lines of force, and these lines of force cut each one of the ten coils in B; since we saw in **Art. 223** that the induced voltage was proportional to the number of lines cut by a coil, the voltage in B is increased. The wattage in A being assumed to be IV, the wattage in B must be *not more* than IV. But $V_1 = 10V$, hence $I_1 = I/10$. The transformer considered is a step-up transformer.

If the 1-volt circuit had been connected to B, the induced voltage in A would be 1/10 volt and as before $IV = I_1V_1$ but now $I_1 = 10I$. This change made the transformer a step-down device.

327. The Doorbell Transformer.—In recent years a transformer has been replacing the dry cells used for ringing doorbells in homes having electric current. The illustrations show such a transformer and a single doorbell circuit.

The transformer is connected in the basement to the 110-volt house circuit and to the bell circuit on the low voltage side. Such a device entirely does away with the annoyance of having the bell circuit out of order because the battery is worn out.

Doorbell transformers are evidently step-down transformers, since the applied voltage is 110 to 120 volts and the doorbells require from 4 to 6 volts. Assuming 120 volts applied and 6 volts required, such transformers have on the primary, the applied voltage side, 20 more turns of wire than are on the secondary side.

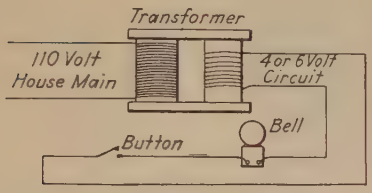


FIG. 211.—Doorbell circuit on a 110 volt main with a transformer. The transformer is shown enlarged.

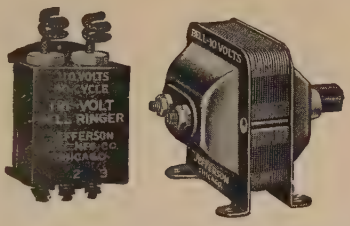


FIG. 212.—Two types of doorbell transformers.

328. Advantage of High Voltage Mains.—Since 110 to 120 volts are generally supplied to houses, the question naturally arises why supply high voltage on the mains and use a transformer to step it down? Let us assume that the houses in a given block, for example, require 100 amp. at 120 volts or 12,000 watts. The generating station is usually some distance away, a half mile, a mile, or even much farther. To transmit 100 amp. at 120 volts a distance of a mile, through a conductor which offers resistance, and so dissipates some of the energy in heating the wire, would require a wire of large diameter if the heating effect is to be made small. But the cost of this large amount of copper would be very great. If an alternating current is used, 10 amp. at 1,200 volts will represent the same energy as 100 amp. at 120 volts.

The heating effect, as we have seen, varies as the square of the current, so the heat loss in the two cases for the same size wire should be as $100^2 : 10^2$ or 100 times greater in the case of

the 100-amp. current. A transformer placed in the block can deliver to the houses 100 amp. at 120 volts while receiving but 10 amp. at 1,200 volts, the transformer itself wasting but a very small amount of the received electrical energy in heat. The advantage of the high-voltage supply mains is in the smaller conductor that can be used, cheapening the cost, and

FIG. 213.—Distributing line transformer.

the lessening in the amount of energy lost in transmission due to heat.

329. The Telephone. *The Transmitter.*—The figure shows a transmitter in cross-section. Two blocks of carbon have finely granulated carbon packed between them. One of the blocks is fastened rigidly to the case and the other is attached to the

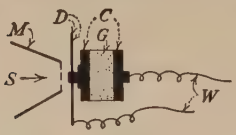


FIG. 214.—Telephone transmitter.

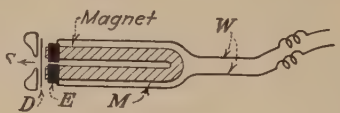


FIG. 215.—Receiver.

metal disk *D*. Any forward and backward movement of *D* produces a varying compression in the granular carbon between the blocks.

The Receiver.—One type of receiver is shown in the figure. The magnet is made of two pieces *M* of hard steel magnetized, and two soft-iron pole pieces *E*, one of which is a north pole and the other a south pole. On each of these is wound a

spool of fine wire, connected in series. The two wires of the telephone line are connected to the ends of the spools.

The diaphragm D is a thin iron disc, clamped at its edge but free to vibrate in the center.

330. A Simple Telephone Circuit.—When the receiver is taken down, a current from a local battery or from the central station flows through the granular carbon of the transmitter and the primary of the small transformer. The vibrations of the disk, due to the voice, cause a change in the resistance of the granular carbon by varying the compression, and the current is therefore increasing and decreasing in the primary

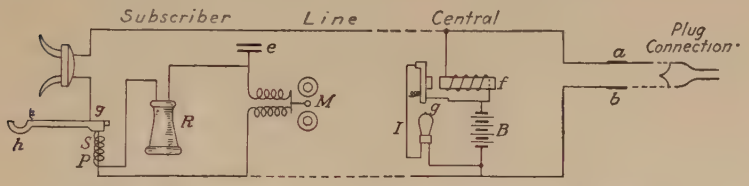


FIG. 216.—One station telephone set, connections for talking.

of the transformer. This changing current produces in the secondary of the transformer an alternating current which flows in the line and in the coil around the permanent magnet in the receiver. The alternating current strengthens and weakens the steel magnet and these variations cause the disk to move to and fro in a manner similar to the vibrating disk in the transmitter at the other end of the line. Thus the original sounds are reproduced in the receiver.

331. Alternating-current Motors.—As has already been stated, the chief advantage of an alternating current is in the *economy* of the transmission. This advantage is so great, that direct currents are seldom found in our homes.

An alternating-current dynamo or generator can be used as a motor, but as it has to be brought up to the exact speed of the generator that is supplying it with current and is not self-starting, such a motor is never used in the home.

The induction motor is a third type of motor used on alternating currents. The explanation of this type of motor is too complicated to be discussed here.

The motors on the vacuum sweepers and washing machines found in our homes are generally so connected that they may be used on either direct- or alternating-current circuits. Note the plate on the motor which will inform you if this is possible.

332. The Kilowatt-hour Meter.—The kilowatt-hour meter as ordinarily found in the home is essentially an induction type of alternating-current motor, the aluminum disk being the rotor. One edge of the disk rotates between laminated iron magnets, energized by windings through which passes the power to be measured. The other edge of the disk passes between the poles of a permanent magnet, shown in the

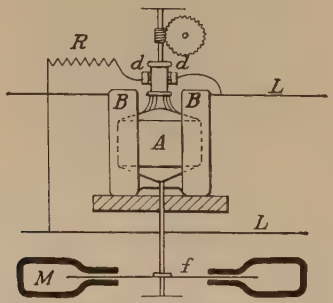


FIG. 217.—A kilowatt-hour meter.

figure, which exerts a constant retarding force on it, thus keeping its speed proportional to the current passing through the meter. Nearly all the house meters read kilowatt-hours directly from the dials. The relative movements of the dial pointers is such that a *complete* revolution of any one pointer is equal to *one division* of the next higher dial.

In reading the dials one should read from *right* to *left*. Owing to the closeness of the observation required and to the fact that not infrequently the pointers are not accurately set, it is necessary to read each dial, except the first, in connection with the one of next lower value. (See instructions for reading gas meters.)

A kilowatt-hour meter is an electric motor so arranged that the revolutions of the disk are recorded on the dials in terms of the kilowatt-hours of electrical energy used.

REVIEW SUMMARY

Faraday discovered that starting or stopping a current in an electric circuit produced a momentary current in a nearby closed circuit. This current is called an induced current and the voltage the induced voltage.

The changing conditions in the primary circuit cause a variation in the number of lines of force in the secondary circuit, and this is the cause of the induced voltage.

The magnitude of the induced voltage is proportional to the number of lines of force cut by the secondary circuit per second.

The energy appearing in the secondary circuit comes from the extra work required of the primary circuit to produce the induction.

Electric generators are of two kinds, direct- and alternating-current. In the alternating-current generator the current flows first in one direction, then in the opposite direction many times per second.

The transformer is a device for transfering electrical energy from one electrical circuit to another with which it is not connected. It is used only with alternating currents and is an application of the induction phenomena already studied.

Since the secondary circuit cannot receive more energy than the primary has, the relation $IV = I_1V_1$ must hold. When V is greater than V_1, I must be smaller than I_1. This transformer is a step-up transformer, giving a higher voltage but a less current. The step-down transformer has these factors reversed.

If the ratio of the number of turns of wire in the primary to the number of turns of wire in the secondary is less than one, the transformer steps up the voltage. If it is greater than one, the transformer steps down the voltage.

Doorbell transformers change a voltage of 110 to 120 volts to a voltage of 4 to 6 volts to be used in the bell circuit.

The main advantage of an alternating current as compared with direct current is the economy of transmitting the electrical energy in the distributing mains.

Electricity at high voltages can be transmitted from a distance to the place where it is to be used and then by means of a transformer the voltage can be reduced to 110 or 120 volts for safe use.

The loss of energy in the line is due to heat and the heat loss for a given conductor increases as the current squared. The mains carry a low current at a high voltage which is distributed at a given locality as a higher current at a lower voltage.

The telephone is an application of the use of the induction effects studied.

The motors in our homes are generally so connected that they may be used with either a direct or an alternating current.

CHAPTER XXXIII

RADIO

333. Radio.—The radio set has become such a commonplace in the home that some understanding of the principles of its operation is desirable for every one.

In heat and light we had occasion to study the behavior of ether waves of certain limited range, and in radio we meet waves of exactly the same nature, differing only in their wave length or frequency. To generate a wave of any kind, energy must be expended, and we are familiar with the transmission of electrical energy from a distant power station to our homes through wires. One of the differences between sending the electrical energy through the wire or through space on the ether is that in the latter case the energy does not travel in one definite direction but is radiated in all directions with the source as the center, very much after the fashion of the water waves when a stone is thrown into still water. These electric waves travel with the velocity of light, 186,000 miles per second or 300,000,000 m. per second. All waves travel with a definite velocity and have a definite frequency and wave length. These are related as follows:

$$V = n\lambda$$

Where V is the wave velocity, n is the frequency and λ is the wave length. If a radio sending station is sending out a wave of length 300 m. and the wave travels 300,000,000 m. in 1 sec., it is evident that there will be 1,000,000 of these wave lengths sent out each second, or the frequency is 1,000,000. The frequency is generally given in cycles per second or in a larger unit kilocycles. We identify the wave sent from a broadcasting station then by saying that its wave length is so many meters or that its frequency is so many kilocycles.

334. The Broadcasting Station.—To broadcast speech or music the sounds are first picked up by a microphone, similar to the familiar transmitter in our ordinary telephones. The energy sent to the microphone is very small and yet it must control the very large amount of energy which is to be radiated in the radio wave. Some multiplying device is necessary and this is a vacuum tube, exactly like, except for size, the tubes in the receiving set which will be described later. These tubes produce alternating currents of high frequency, which are necessary to cause the radiation of the radio waves from the antenna. Before these waves are sent out they must be modulated, and as the modulation at the sending station is just the reverse of that at the receiving end, an explanation will be given later. The waves sent from a given station have also a definite wave length, for example, Station KGO at Oakland, sends out a wave of 377.2 m. while KJR at Seattle broadcasts on a wave of 309.2 m or 970 kilocycles.

335. The Receiving Station.—The receiving station, if it is to pick up the weak energy received by the antenna from some distant broadcasting station, must be tuned or put in resonance with the receiving wave. We are familiar with the tuning of a piano. If a wire is tuned so it vibrates or has a frequency of 256 vibrations per second and a singer sings a note of pitch 256, the string on the piano will pick up the weak energy of the sound waves and be set in vibration. It is tuned or in resonance with the voice. Tuning then of the receiving set will make it more sensitive and also less able to respond to a wave of a different frequency.

When the receiving antenna is in tune or resonance with the radio wave, the current in the antenna is a maximum. The tuning is done by a variable condenser and some form of coil or inductance. When the circuit is tuned the energy received sets up varying currents in the coil and there is a varying voltage at the coil terminals. This voltage is of the same high frequency as the radio wave, and its pulsations are so rapid that no head phone or loud speaker would be able to follow them and the ear would not hear any sounds from such rapid vibrations. The high-frequency radio waves picked

up by the antenna must be changed into low-frequency sound waves just as at the sending station the low-frequency sound waves had to be changed into high-frequency radio waves.

Figure 218*a* is a representation of a low-frequency sound wave sent into the microphone at the sending station; *b* represents the high-frequency radio wave sent out to the receiving station. It will be seen that this wave has a high frequency but that its intensity follows the variations in the intensity or amplitude of the sound wave. This wave is said to have been "modulated." If we assume the wave in *a* has a frequency of 1,000 vibrations per second, and the radio wave was

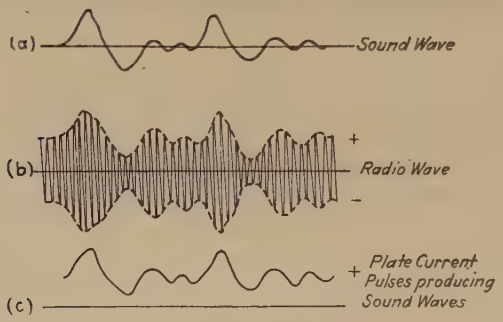


FIG. 218.—*a*, *b*, *c*.

300 m. long, then the frequency of the radio wave would be 1,000,000 vibrations per second, or it would have a frequency 1,000 times higher than that of the sound wave.

When this modulated high-frequency wave is received by some form of rectifier as a crystal or vacuum-tube detector the current received in the head phone or loud speaker will vary as in *c*. It can be seen that this current variation having the same form as the original sound wave will throw the diaphragm of the head phones into motions exactly similar to those of the microphone and these like motions will reproduce the original sounds.

336. The Vacuum Tube.—The vacuum tube consists of a tube with a filament *F*, which may be heated by a current from the battery *A* or from the *A* battery as this is usually called (Fig. 219) a plate *P* and a grid *G* of wire gauze. The plate *P*

is connected with the plus side of battery B in the figure, usually called the B battery. Current from B will flow from the plate to the hot filament or *electrons* will flow from the hot filament to the plate. If the grid G is connected to the negative side of a battery the flow of electrons from filament to plate is *decreased;* if the grid is connected to the plus side of a battery, the flow of electrons from filament to plate is *increased.* The grid acts as a sort of trigger somewhat as the trigger in a gun, which can, by the expenditure of a small amount of energy in pulling it, liberate a large amount of energy in the gun. The grid is the trigger which controls the amount of current flowing from plate to filament. In the receiving set the grid is connected to the input or receiving circuit and is made alternately positive and negative by the alternating electromotive forces set up by the incoming radio wave. The head phones are placed in the plate and B circuit.

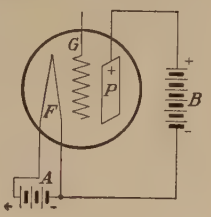


FIG. 219.—The three-electrode tube.

The A and B batteries are now being largely replaced by connecting the radio set to the alternating-current circuit in the home through proper devices.

337. The Vacuum Tube as a Detector.—Assume the receiving antenna, T (Fig. 220) picks up a signal. Oscillations are set up in the tuned circuit LC. The absorbed radio wave produces high-frequency alternating voltages between the terminals of L and these are impressed on the grid, making it alternately plus and minus; the frequency of the changes being the same as those in the radio wave. If, now, the plate current is normally at the proper value, the increase in the plate current due to the flow of electrons when the grid is momentarily positive is *greater* than the decrease of the plate

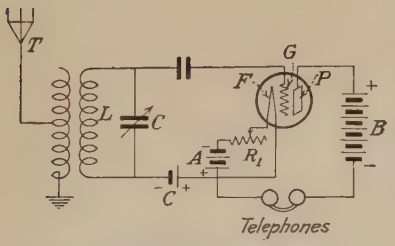


FIG. 220.—A simple receiving set-up.

current when the grid is negative, so that the *average* plate current is increased while the signal or impulse is passing. This means that the head phones or loud speaker is receiving a greater current than it would otherwise.

The figure shows the simultaneous values of (1) the high-frequency radio oscillations of the grid voltage; (2) the high-frequency variations in the plate current; and (3) the direct low or audio frequency of the oscillations received by the head phones or loud speaker.

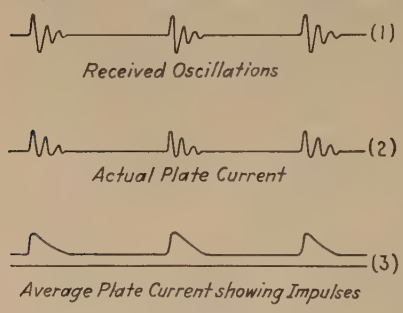


Fig. 221.

338. Audio and Radio Amplification.—It is usually desirable to increase the weak radio wave before reaching the detector tube and also to increase the audio wave after leaving the detector tube so as to obtain greater volume of sound from the loud speaker.

(*a*) *Radio Amplification.*—Increase in the strength of the radio wave to be detected is accomplished by impressing the incoming oscillations on the grid of a three-electrode tube. The plate current of this amplifier tube is connected to the grid circuit of the detector tube, usually through a transformer consisting of a primary and secondary coil without any iron core. This is a one-step amplifier. Two or more radio amplifications may be obtained by inserting more amplifying tubes each with its own transformer.

(*b*) *Audio Amplification.*—To increase the audio wave, a three-electrode tube is inserted after the detector tube. The plate circuit of the detector tube is connected to the primary of a small iron core transformer. This transformer is a step-up transformer; the voltage in the secondary is therefore greater than that in the primary. This increased voltage is applied to the grid circuit of the amplifying tube and the plate of this tube includes the loud speaker. This set-up is a single-stage audio amplification. Two or more stages of

audio amplification can be had by adding in a like manner other tubes each with its transformer.

339. The Loud Speaker.—The loud speaker is simply an amplified head phone. It consists of a strong permanent magnet, a coil to carry the amplified current from the last stage of an amplifier, a soft iron armature which vibrates in the field of the magnet as the current varies in the coil, and a flexible diaphragm fastened to the armature in such a way that its motions are the same as those of the armature.

Some General Review Questions

1. Why does molasses candy "whiten" when it is pulled?
2. Which are warmer in sunlight, white or black garments? Why?
3. The top of a cake of ice in a refrigerator melts faster than the bottom part. Why?
4. Sunlight can warm a room by passing through the frost on the windows and not melt it. Explain.
5. Why should a hot lamp chimney sometimes crack when a sudden cold blast of outside air strikes it?
6. Why are hot-water radiators built in sections, dust catchers, and not in one solid section?
7. What properties are shown by molasses candy when it breaks when struck but will bend in the fingers?
8. Why is iron used in preference to brass or other metals for ironing garments?
9. Why will your voice carry farther over water than over land?
10. Cherries bottled in round glass jars always look larger than they really are. Why?
11. What evidence do we have that notes of various pitch travel at the same speed in air?
12. What is the effect of an increase in temperature on the pitch of a violin string?
13. Why should sawdust be a better heat insulator than the solid wood?
14. Asbestos is a better conductor of heat than air. Why then are hot-air furnace pipes covered with asbestos?
15. If a 125-lb. woman can just float, what is her volume?
16. If there were moisture on the face, would fanning produce any feeling of coolness when the humidity is 100 per cent?
17. Two persons are carrying a heavy suitcase. For the exertion of the least effort should they walk close together or far apart as possible?
18. After water has been "brought to a boil" will eggs become hard any quicker when the boiling is gentle rather than violent?
19. Why does the reverberation in an empty room disappear when the furniture and rugs are installed?

20. Why is the quality of the note from an open organ pipe different from that of a closed pipe of the same pitch?

21. Sirius, the brightest star is $52 \times 10''$ miles distant. If it had been annihilated 2 years ago, would we know it now?

22. Glass transmits all the visible light but does not transmit the longer heat waves. Why does glass make a good fireplace screen and yet is used for "hothouses?"

23. The handle of a hammer is driven into the hammer by pounding the end of the handle rather than the hammer. Why?

24. Why will a cord supporting a weight generally break if the weight be lifted and then let fall?

25. Atropine placed in the eyes enlarges the pupils. Why is vision then less distinct?

26. How would you determine whether your spectacle lenses are concave or convex?

27. Why do thermometers have a bulb at one end? Would a closed uniform tube answer as well?

28. Give three reasons why mercury is a more suitable substance for thermometers than water.

29. Is the heart a suction pump or a force pump?

30. How does the structure of the backbone lessen jars?

31. Name the levers in the body.

32. Why is "blueing" used to whiten clothes?

33. Why does the oilcloth feel colder than the wood floor?

34. Why is it necessary to force a knife under one part of the cover of a fruit jar before the cover will come off? Would the same result be effected if the air around the cover were removed?

35. Why will a swinging door open slightly if someone opens a door quickly in another part of the room?

36. What causes the water to rise in a coffee percolator?

37. Should the bottom of the teakettle be kept polished?

38. Why are the lights in a home wired in parallel?

39. How far away is a lightning storm if 15 sec. elapsed between the flash and the sound of the thunder?

40. Why should putting our hand over the transmitter of a telephone enable us to hear better in the receiver when the room is noisy?

41. Why do the bass horns in a band have to be larger than any cornet?

42. Why in jumping from a height is it wise to bend the knees on alighting?

43. Why is it possible to remove snow from the shoes by kicking the feet against the doorstep?

44. Why does a garden hose which is not straight twist and turn when the water is turned on?

45. Why lower the handle of the lawn mower when cutting long grass?

46. A newly rich house owner had all the hot-water radiators gold plated. What was the result in heating the rooms?

47. The newer types of some gas ovens are lined on the inside with enameled iron. Is this any advantage?

48. Will touching the ends of the two wires from the doorbell battery give you a shock?

49. Why not have the chimney on the outside of the house?

50. Why is it a poor practice to use a paper blanket on the ice in a refrigerator?

51. Why is it necessary to heat the burner of a gasoline stove and most oil stoves before lighting the stove?

52. Why is it possible to see your image in the store window?

53. Why are some blues and greens indistinguishable from each other in candle light?

54. Why does pouring a little water upon the piston of a dry pump help the action of the pump?

55. Why do we use, first paper, then wood, then coal in starting the furnace fire?

56. When the top of a Mason fruit jar sticks, we can often loosen it by immersion in hot water for an instant. Why?

57. Why does moisture condense on the inside of the windows in the kitchen?

58. Why is the top of a water wave white, a "white cap," while the unbroken water is a bluish-green?

59. Is the evidence from our senses always reliable? Illustrate.

60. Why does it rest the eye, after reading a book, to look at a distant object?

61. How is the atmosphere heated?

62. What are the advantages of standard time?

63. Why do not colors look the same in artificial light as they do in sunlight?

64. Where is the potential and the kinetic energy in your watch?

65. What type of thermometer did Byrd take on his expedition to the South Pole? Why?

66. What is the difference between light and radiant heat?

67. If you have hot-water pipes parallel to the floor in a window seat, what simple means could you take to get more heat energy into the room?

68. When a gram of ice has received heat, how do you know the energy absorbed is not in the water in the form of kinetic energy?

69. In an electric refrigerator where does the heat taken from the food go?

70. Name some of the ways in which low and high humidity affect one.

71. Why should a pitcher of ice water "sweat?"

72. Why does the sound stay longer in an empty room than in the same room when furnished?

73. Why will clapping your hands make a noise when waving of your arms does not?

74. Why is it harder to start an automobile than to keep it going on a level road?

75. Why is it dangerous to face backward when getting off a moving car?

76. Why cannot the door of a closet be slammed shut?

77. Two water tanks are of the same height and have the same area on the bottom. One is cylindrical and the other is like an inverted cone. What are the relative pressures on the bottoms, both tanks being full of water?

78. Two steam heating pipes connected to the boiler have diameters of 1 to 2. What is the pressure on the cross-sections of each?

79. What property of liquids makes it possible to transmit pressure in all directions while a solid can transmit pressure in one direction only?

80. A 115-lb. woman can just float in fresh water when almost completely submerged. Can you find her volume?

81. What accounts for the entrance of water into a lift pump?

82. Campers punch two holes in the cover of a can of condensed milk. What is the purpose of each hole? Is the relative position of the holes important?

83. Why should sudden and large changes in altitude sometimes produce serious body disturbances?

84. Why are alcohol thermometers used? Are they apt to be more or less accurate than mercury thermometers if used as house thermometers?

85. How could a bar made of two dissimilar metals, an electric bell, a dry cell, and contacts be used as an alarm to indicate a fire in the attic?

86. If in place of many small metal shingles, the roof of a house should be covered with one continuous sheet of metal, would there be any marked disadvantage?

87. Does the warm air over a stove rise or is it pushed up? Why?

88. Your neighbor's burning house 30 ft. distant may break the windows in your home. Explain.

89. A pail filled with water hangs from a spring balance. A piece of ice weighing 1 lb. is placed in the pail. What change in reading of the balance occurs? Would a 1-lb. piece of lead produce the same effect?

90. If three spring balances pull in different directions away from the same point, how does the resultant of any two of these pulls compare in magnitude and direction with the third pull?

91. Why do lawn sprinklers rotate?

92. Why does a ball roll down hill?

93. What is meant by audio and radio frequencies?

94. Is every vibrating body producing a sound? Explain.

95. A camper sets his watch by the sound of a steam whistle which blows at 12 o'clock noon and is 3 miles away. The air is at 85° F. What error is there in his time?

96. The color characteristic of light corresponds to what characteristic of sound?

97. What will be the appearance of a red ribbon viewed in pure blue light?

98. What is the "fuel" in a dry cell?

99. Why do not the flashlight cells—dry cells—last as long as the larger dry cells?

100. What does the blackening of an incandescent lamp indicate? Is it economy to discard it?

101. Will the same illumination be produced in a room by six 25-watt lamps as by one 150-watt lamp? Why?

102. It may be assumed that the air in an oven has the same temperature as the grates. Touching the grate will give a burn but thrusting the hand into the oven will not. Why?

103. If tungsten lamps give more of the red end of the spectrum than sunlight what hues seen under their light will be most distorted?

104. Will a blond or brunette look the better under a bluish purple sunshade? Will the appearance of either be improved?

105. How can the pitch of the sound from a phonograph be increased?

106. How does the piano tuner tune a piano since the lengths of the strings are constant?

107. An old saying is that "if you can count three between the flash of lightning and its thunder clap the storm is not dangerously near." How far away is the thunder cloud?

108. Arrange two plane mirrors so that you see the back of your dress.

109. What is the hue of a blue dress when seen by the light of a kerosene lamp?

110. Given two push buttons, one electric bell and a battery, sketch the circuit so that each button may ring the bell independently of the other.

111. If the heart pumps about 5 pt. of blood per minute into the arteries and three times as much when you exercise violently—what are the approximate relative amounts of work performed?

112. We stop down our camera lens when the light is very bright. Have we any such arrangement in the eye for caring for too much light?

113. What is the advantage of two eyes?

114. Why do rubber balls bounce?

115. Why can't you skate on glass? It is smoother than the ice.

116. Why when walking toward the rear of a street car do you tend to be thrown backward as the car stops?

117. Why do snowflakes fall more slowly than raindrops?

118. Why do we sometimes see two images in a window pane?

119. Why is snow white but ice transparent?

120. Why can more musical notes be produced on a violin with four strings than on a piano which has many?

APPENDIX A

SOME ARITHMETICAL RELATIONS AND CONSTANTS

1. Ratio of Quantities.—The relative magnitude of two quantities is called their *ratio* when expressed by the indicated quotient of the first by the second.

Thus the ratio of a to b is a/b, or $a \div b$ or $a : b$.

2. Proportion.—In order for four quantities A, B, C, D to be in proportion A and B must be of the *same kind* and C and D of the *same kind* (but C and D need not be of the same kind as A and B). And also, the ratio of the first two must be equal to the ratio of the second two.

Thus the proportion may be written:

$$\frac{A}{B} = \frac{C}{D} \text{ or } A : B :: C : D.$$

A and D are called the *extremes* and B and C the *means*. The product of the extremes must equal the product of the means.

The proportion above is called a direct proportion, while the one below is an indirect or inverse proportion.

$$A : B :: D : C.$$

EXAMPLES OF DIRECT AND INDIRECT PROPORTIONS

1. The weight of a given rod will *vary* as its length. If 3 ft. of this rod weighs 10 lb., what will be the weight of 15 ft.?

$$3 : 15 :: 10 : x \text{ (Direct proportion).}$$
$$3x = 150,\ x = 50 \text{ lb.}$$

2. A foot rule must be applied twelve times to measure the length of a certain room. If a 2-ft. rule is used, it will have to be applied six times, while a yard stick will have to be applied four times only. *Doubling* the length of the rule, *halves* the number of times it must be applied. This relation is expressed by saying that the number of times a rule will have to be applied to measure a given length varies *inversely* as the length of the rule.

$$1 : 2 :: 6 : 12.$$

3. The number of times a 2-qt. measure will have to be used to empty tubs of water will vary directly as the size of the tubs.

Number of dips for tub A : Number of dips for tub B :: Size A: Size B.

4. The number of dips to empty a given tub will *vary inversely* as the size of the dipper.

Dipper A ; dipper B :: Number of dips with B: number of dips with A.

3. Some Constants.—The ratio of the circumference of a circle to its diameter equals 3.1416, called π.

The circumference of a circle $= \pi D = 2\pi R$, R = the radius.

Area of a circle $= \pi R^2$.

Area of a sphere $= 4\pi R^2 = 12.57R^2$.

Volume of a sphere $= \frac{4}{3}\pi R^3 = 4.189R^3$.

Lateral area of a cylinder $= 2\pi R \times$ height of cylinder.

Volume of a cylinder $= \pi R^2 \times$ height of cylinder.

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